US009490000B2

(12) **United States Patent**
Apalkov et al.

(10) **Patent No.:** **US 9,490,000 B2**
(45) **Date of Patent:** **Nov. 8, 2016**

(54) **METHOD AND SYSTEM FOR PROVIDING THERMALLY ASSISTED MAGNETIC JUNCTIONS HAVING A MULTI-PHASE OPERATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 44 days.

(21) Appl. No.: **14/563,307**

(22) Filed: **Dec. 8, 2014**

(65) **Prior Publication Data**

US 2015/0294707 A1 Oct. 15, 2015

Related U.S. Application Data

(60) Provisional application No. 61/978,150, filed on Apr. 10, 2014.

(51) **Int. Cl.**

G11C 11/16	(2006.01)
H01L 43/10	(2006.01)
H01L 43/08	(2006.01)

(52) **U.S. Cl.**
CPC ***G11C 11/1675*** (2013.01); ***H01L 43/08*** (2013.01); ***H01L 43/10*** (2013.01)

(58) **Field of Classification Search**
CPC . G11C 11/1675; H01L 27/222; H01L 43/02; H01L 43/10
USPC 365/158
See application file for complete search history.

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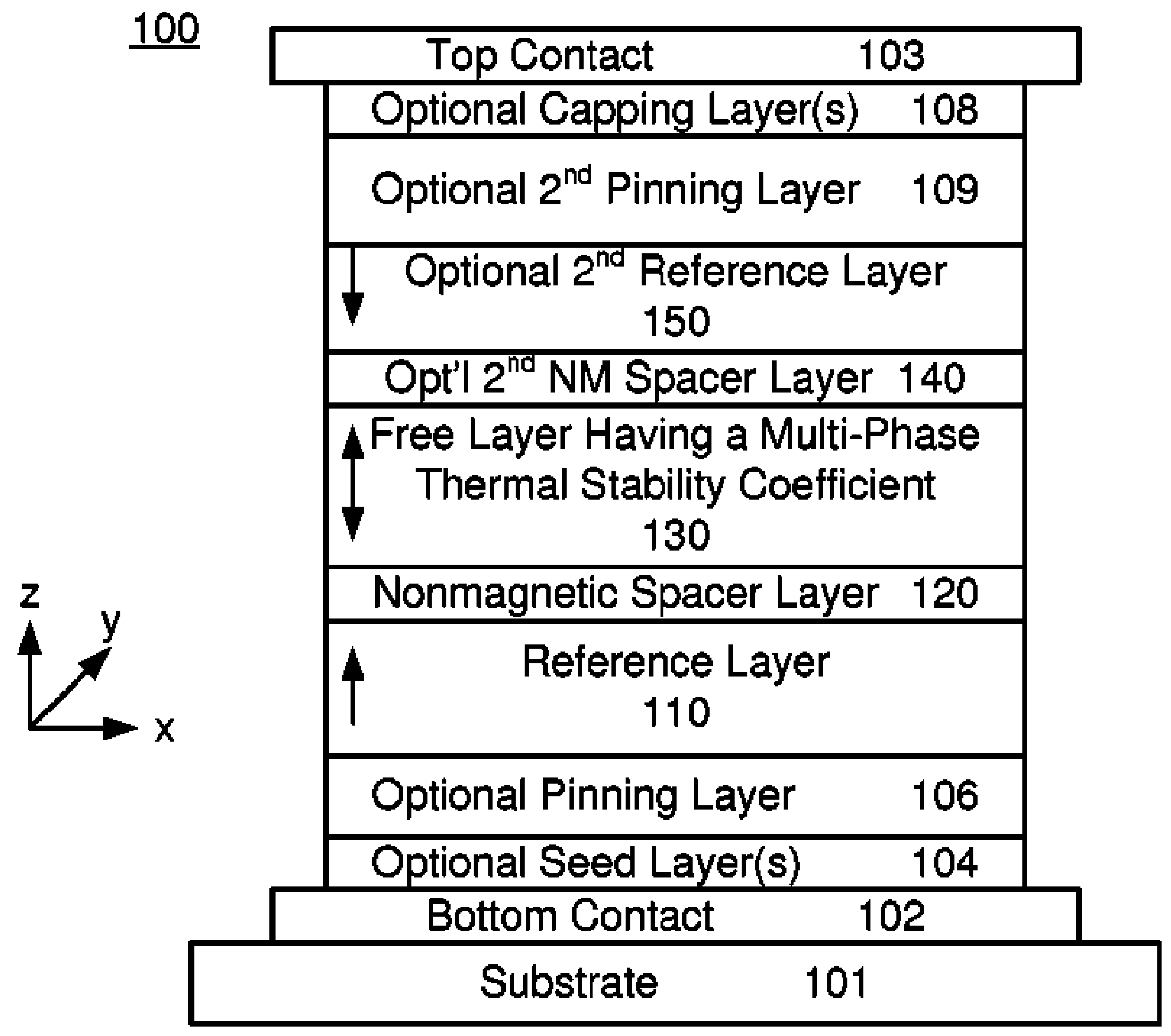
(57) **ABSTRACT**

A magnetic junction usable in magnetic devices is described. The magnetic junction includes at least one reference layer, at least one nonmagnetic spacer layer and a free layer. The nonmagnetic spacer layer(s) are between the reference layer(s) and the free layer. The free layer has a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases. A first phase magnetic thermal stability coefficient has a first slope below a first temperature. A second phase magnetic thermal stability coefficient has a second slope above the first temperature and below a second temperature greater than the first temperature. The first and second slopes are unequal at the first temperature. The magnetic thermal stability coefficient is zero only above the second temperature. The free layer is switchable between stable magnetic states when a write current passed through the magnetic junction.

17 Claims, 9 Drawing Sheets



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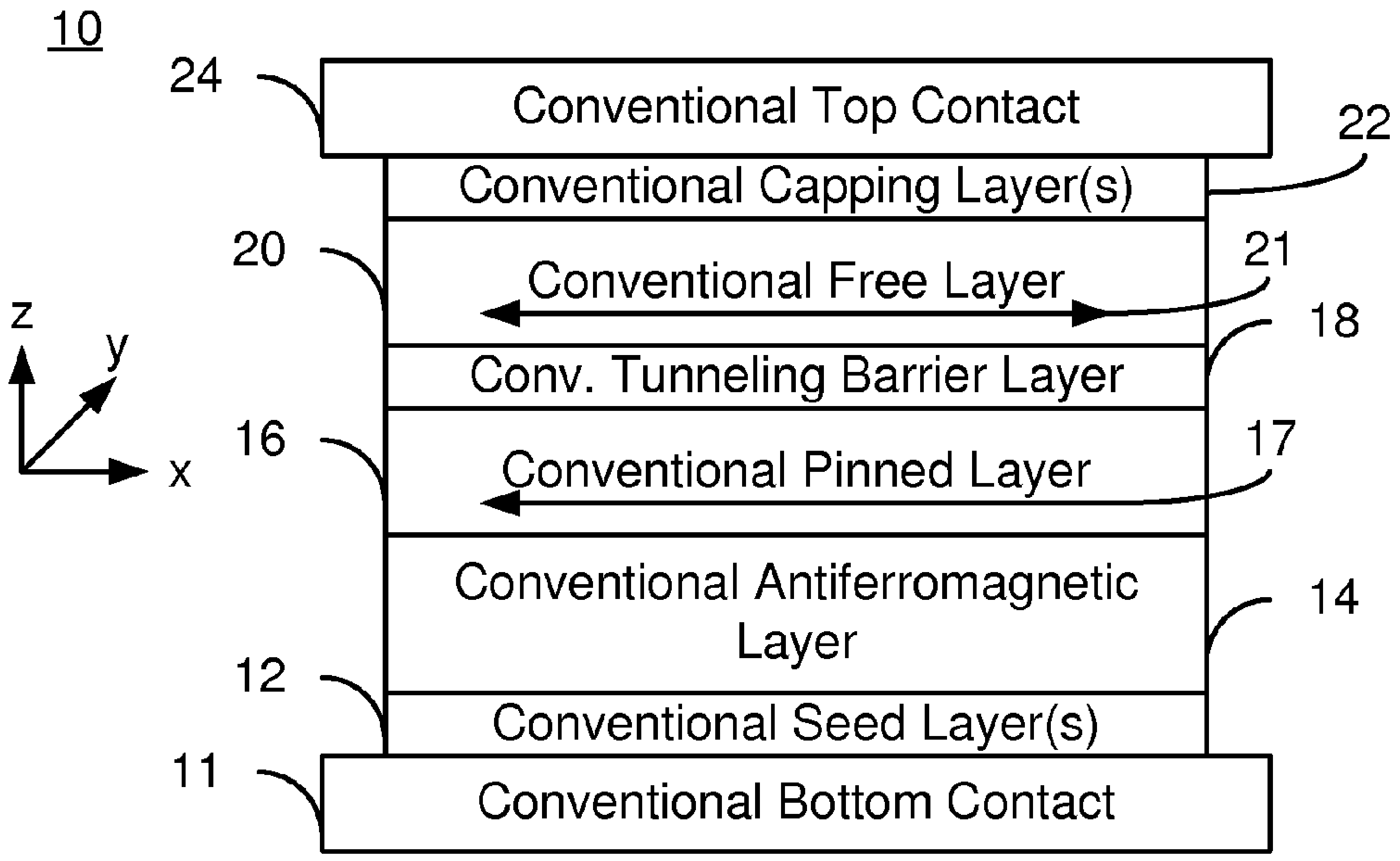

Prior Art
FIG. 1

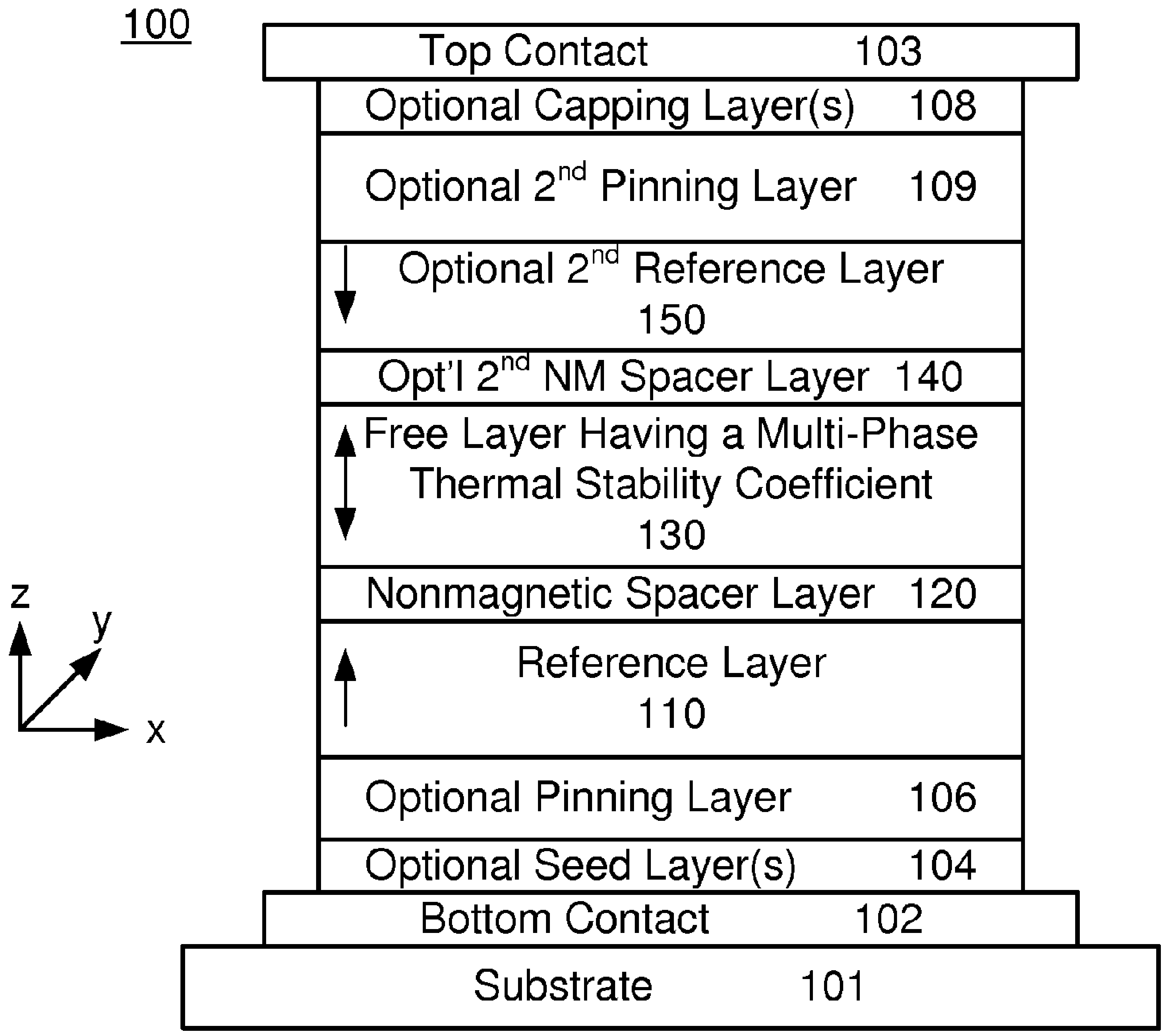

FIG. 2

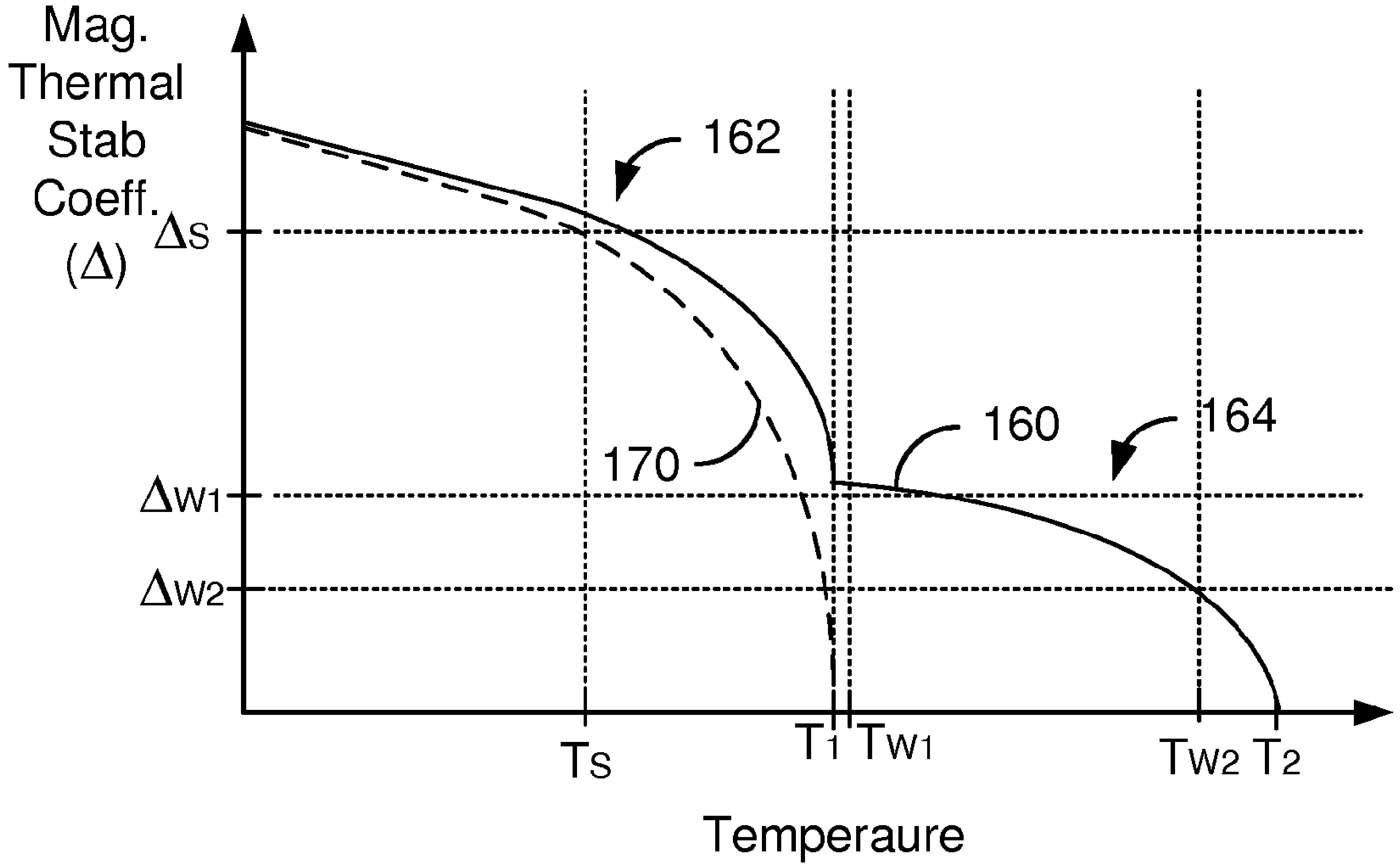
Mag.
Thermal
Stab
Coeff.
(Δ)
ΔS
ΔW1
ΔW2
162
160
164
170
TS
T1
TW1
TW2
T2
Temperaure

FIG. 3A

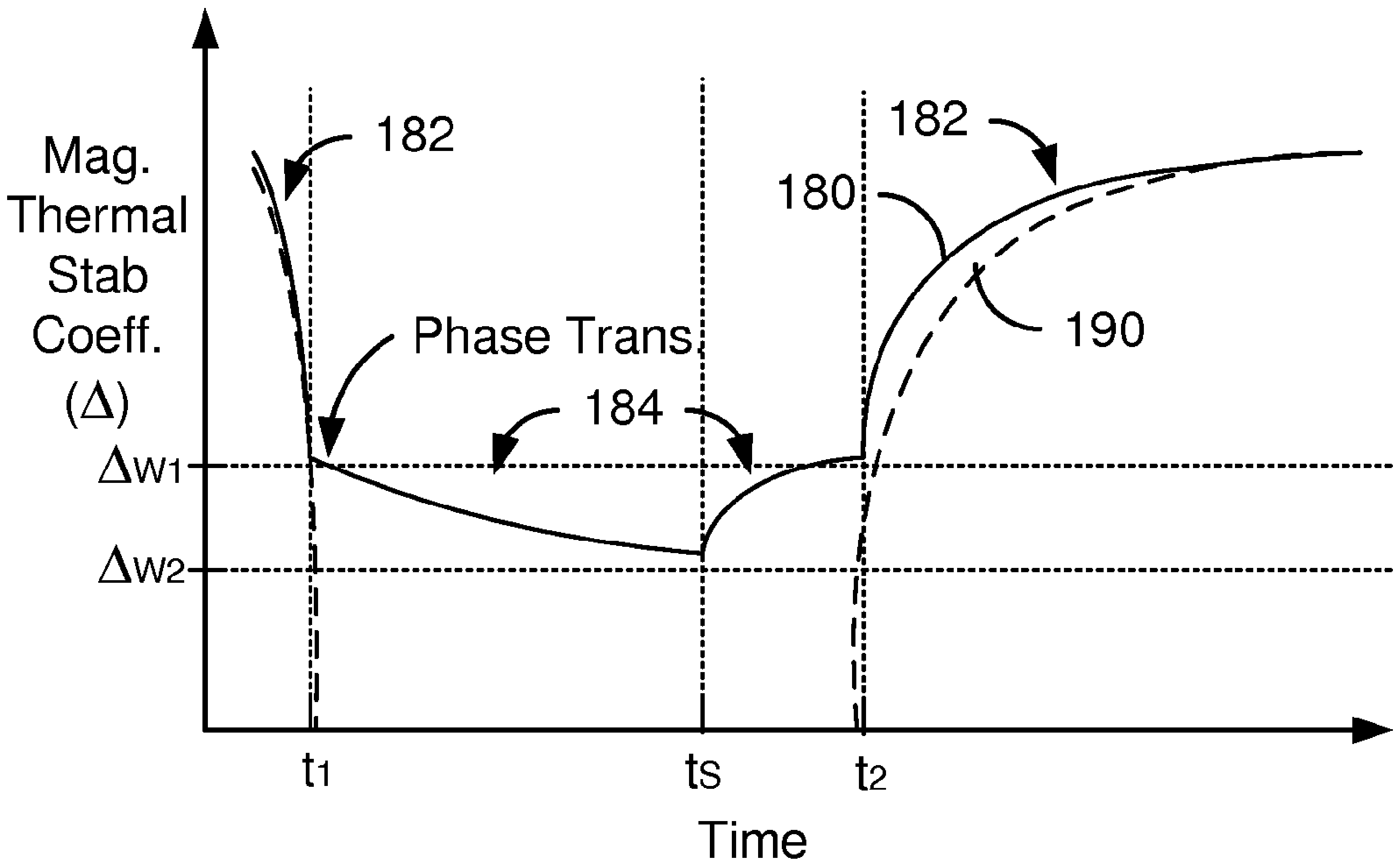
Mag.
Thermal
Stab
Coeff.
(Δ)
ΔW1
ΔW2
182
182
180
190
Phase Trans.
184
t1
tS
t2
Time

FIG. 3B

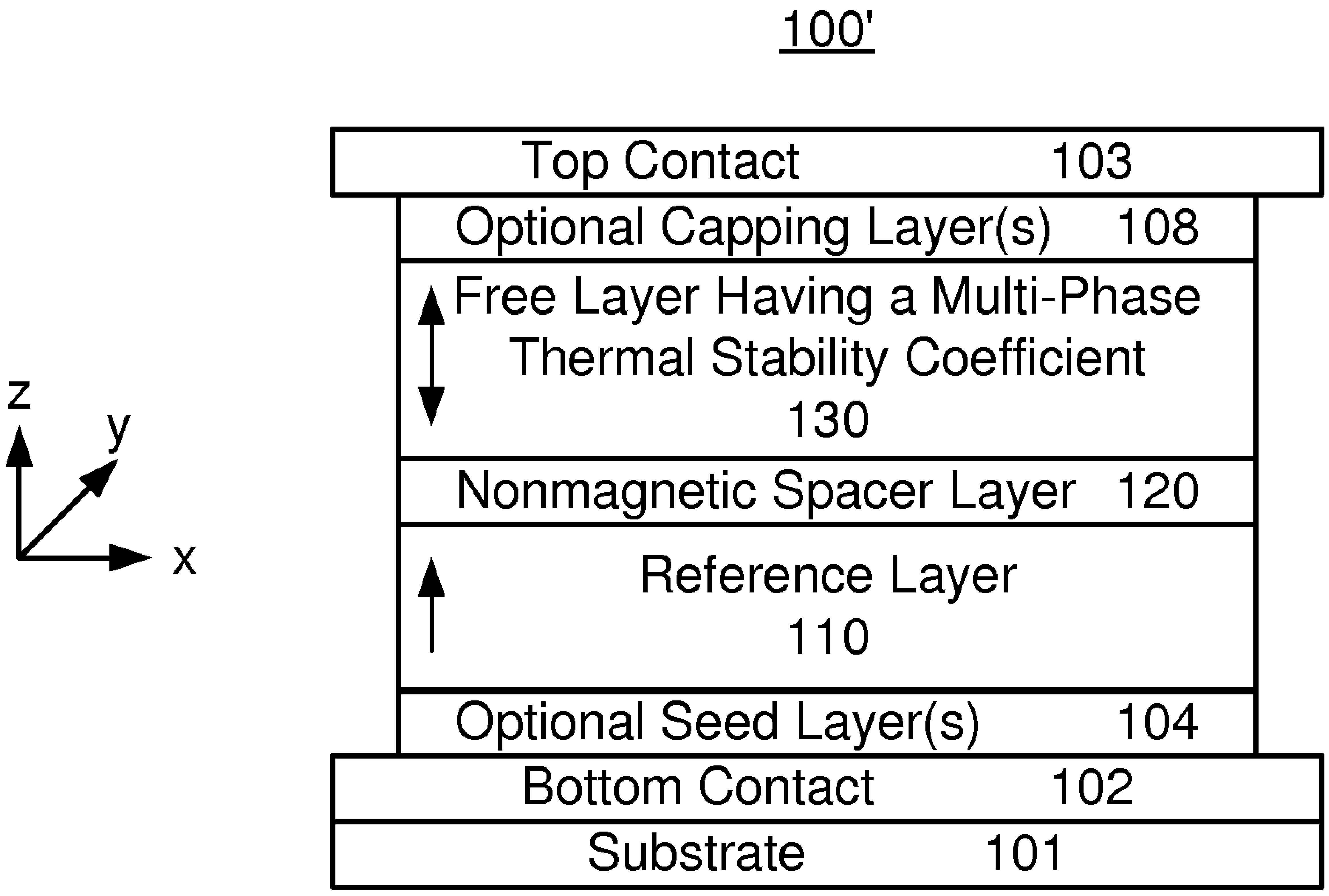
100'
Top Contact 103
Optional Capping Layer(s) 108
Free Layer Having a Multi-Phase Thermal Stability Coefficient 130
Nonmagnetic Spacer Layer 120
Reference Layer 110
Optional Seed Layer(s) 104
Bottom Contact 102
Substrate 101
z
y
x

FIG. 4

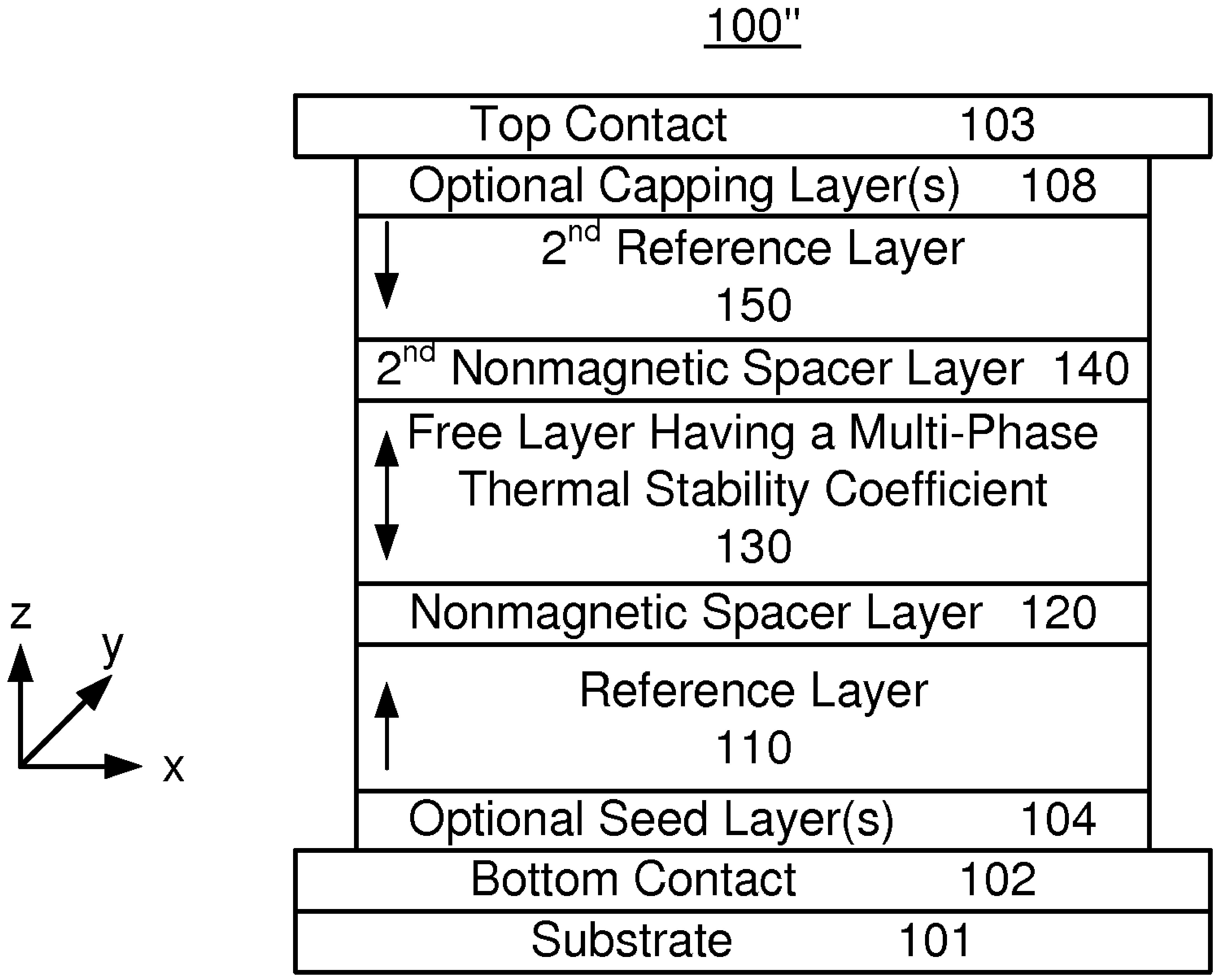
100''
Top Contact 103
Optional Capping Layer(s) 108
2nd Reference Layer 150
2nd Nonmagnetic Spacer Layer 140
Free Layer Having a Multi-Phase Thermal Stability Coefficient 130
Nonmagnetic Spacer Layer 120
Reference Layer 110
Optional Seed Layer(s) 104
Bottom Contact 102
Substrate 101
z
y
x

FIG. 5

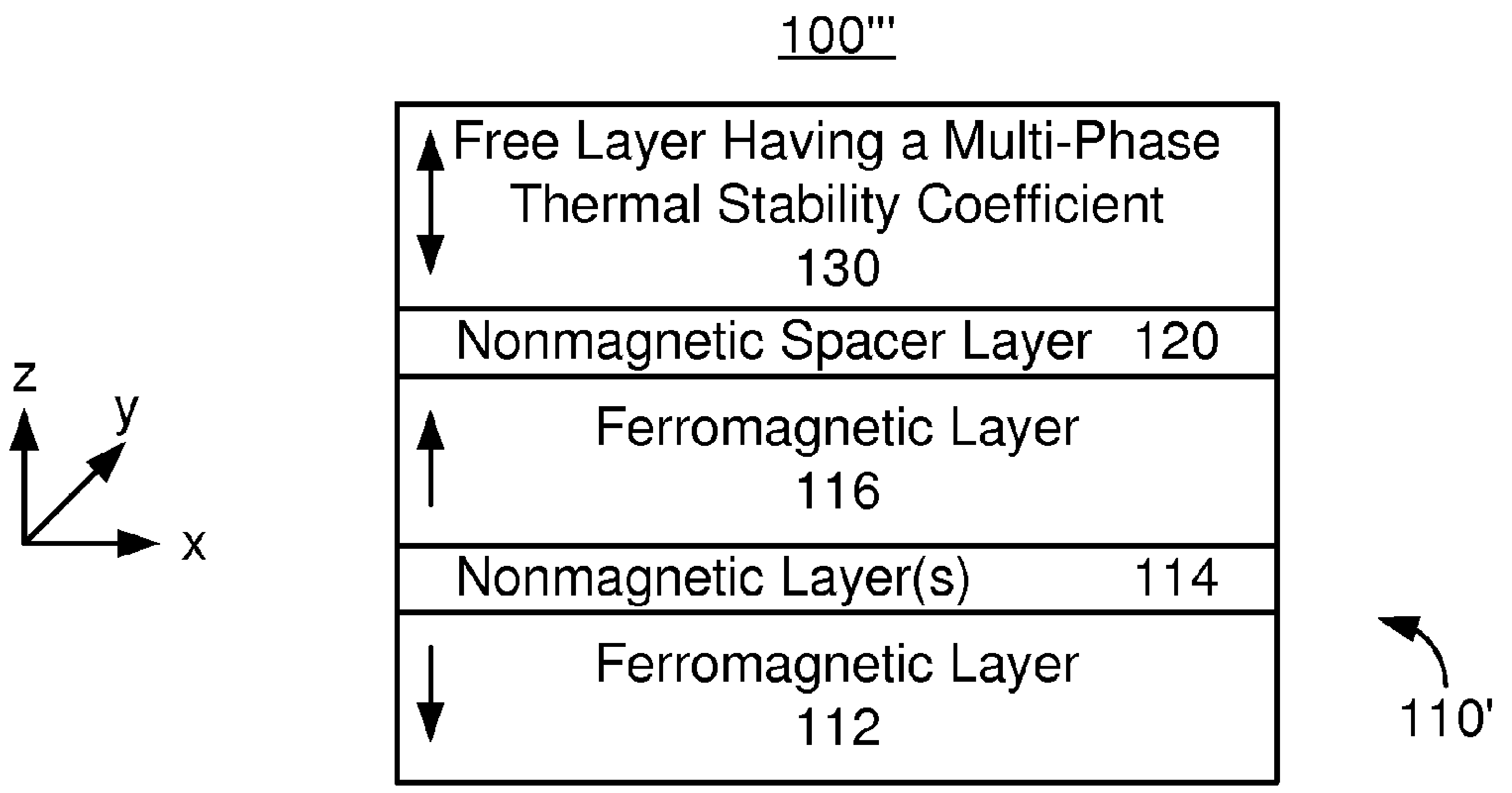
100'''
Free Layer Having a Multi-Phase Thermal Stability Coefficient 130
Nonmagnetic Spacer Layer 120
Ferromagnetic Layer 116
Nonmagnetic Layer(s) 114
Ferromagnetic Layer 112
110'
z
y
x

FIG. 6

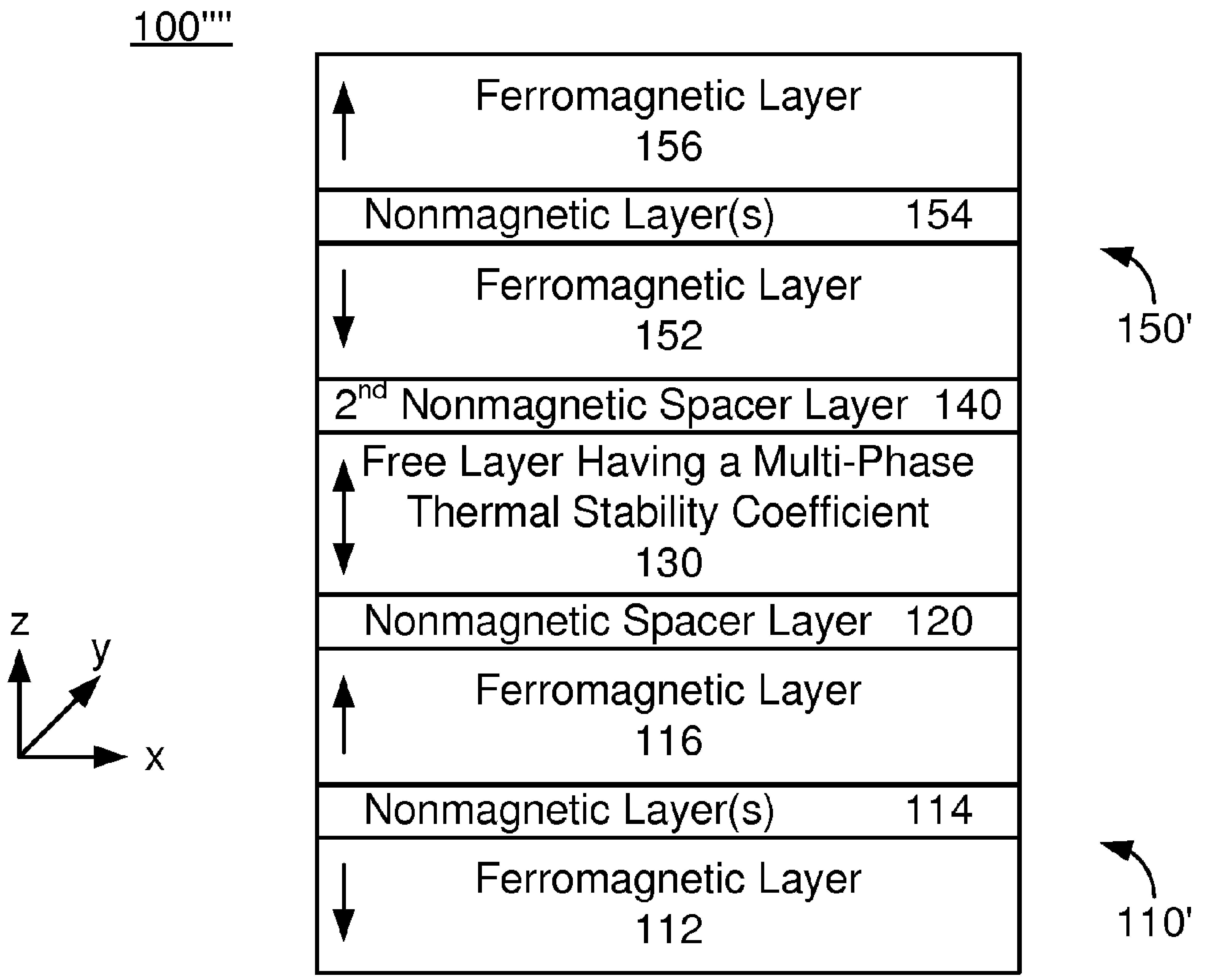
100''''
Ferromagnetic Layer 156
Nonmagnetic Layer(s) 154
Ferromagnetic Layer 152
150'
2nd Nonmagnetic Spacer Layer 140
Free Layer Having a Multi-Phase Thermal Stability Coefficient 130
Nonmagnetic Spacer Layer 120
Ferromagnetic Layer 116
Nonmagnetic Layer(s) 114
Ferromagnetic Layer 112
110'
z
y
x

FIG. 7

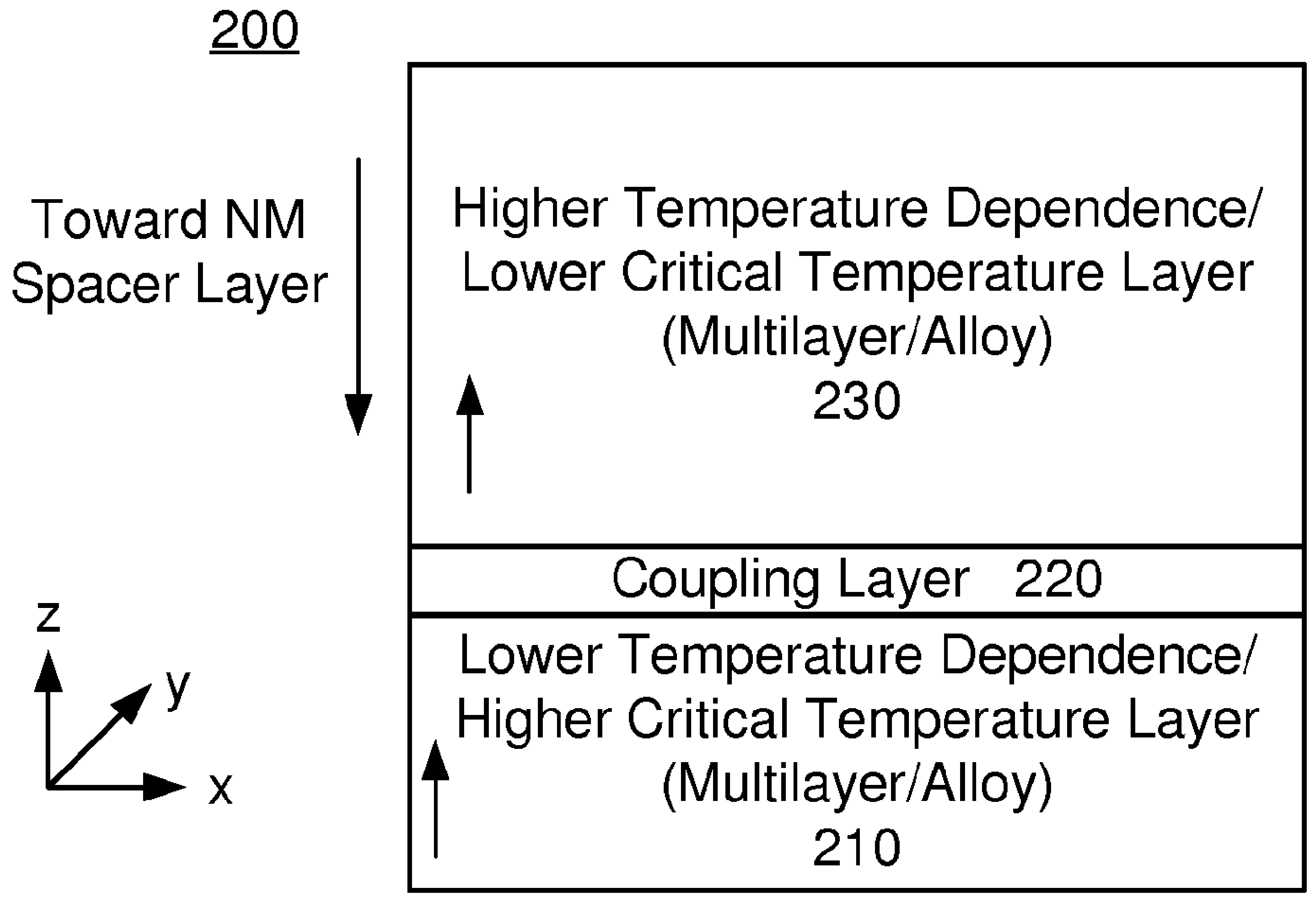
200
Toward NM Spacer Layer
Higher Temperature Dependence/ Lower Critical Temperature Layer (Multilayer/Alloy)
230
Coupling Layer 220
Lower Temperature Dependence/ Higher Critical Temperature Layer (Multilayer/Alloy)
210
z
y
x

FIG. 8

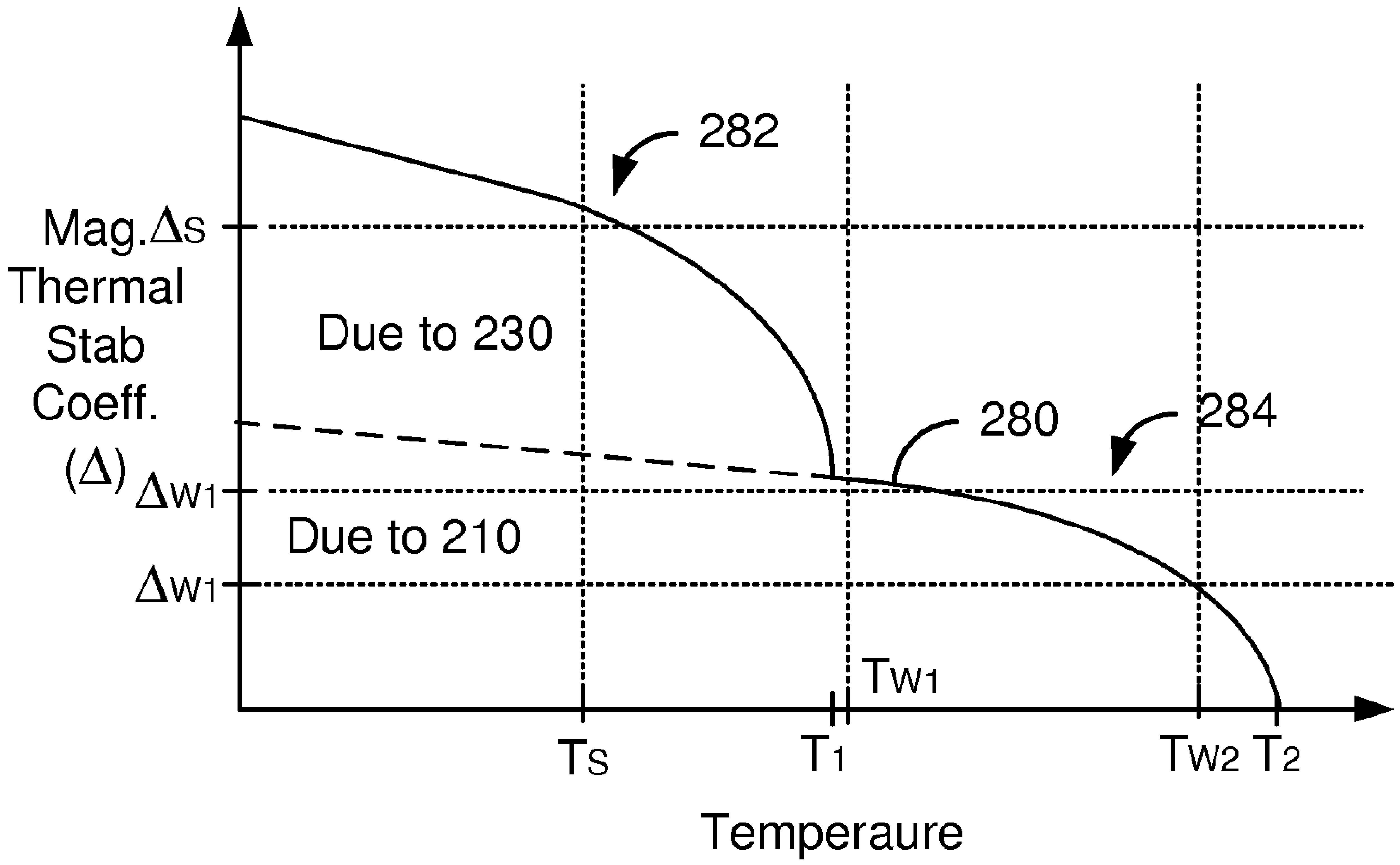
282
Mag. Δs
Thermal Stab Coeff. (Δ)
Due to 230
280
284
Δw1
Due to 210
Δw1
Tw1
Ts
T1
Tw2
T2
Temperaure

FIG. 9

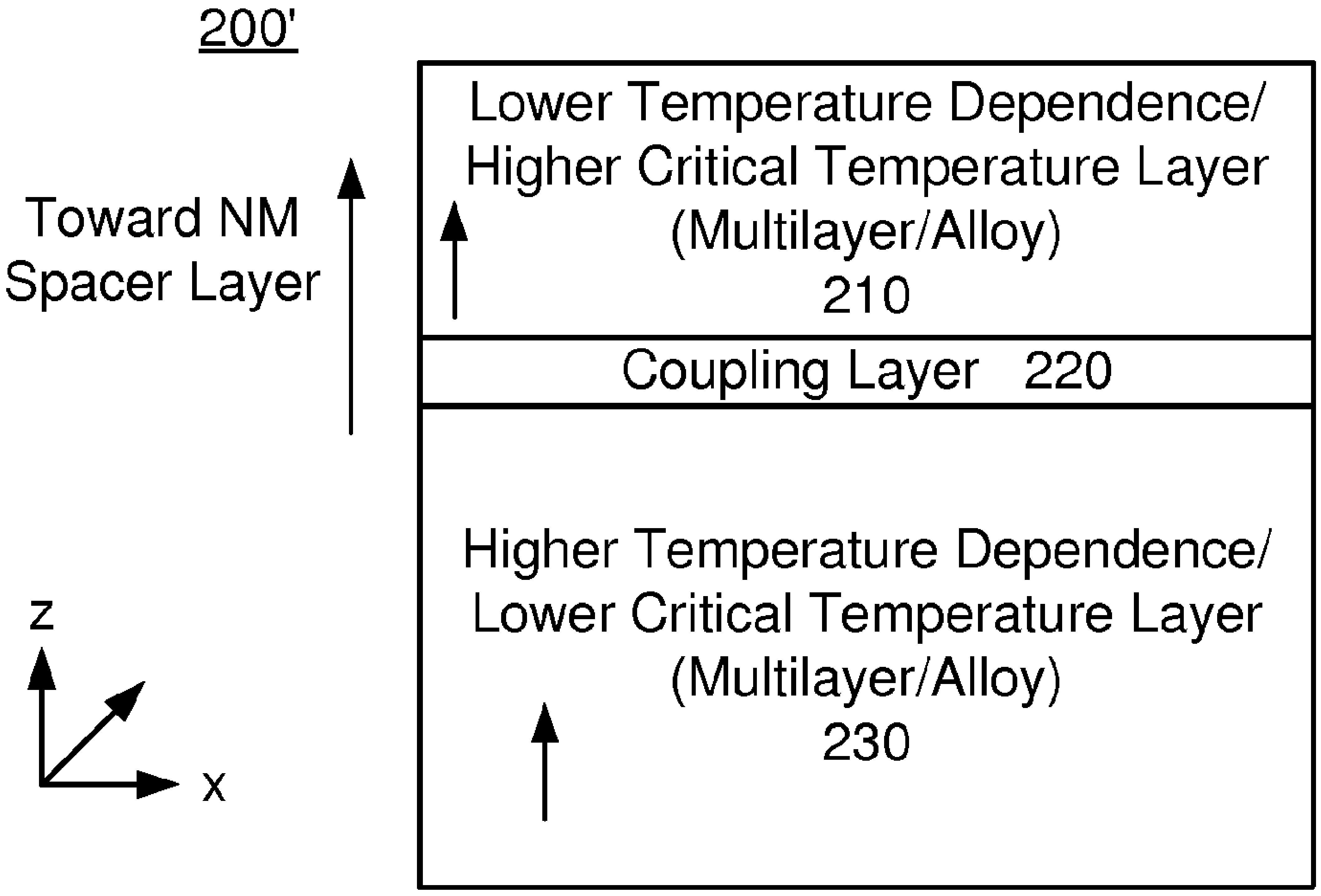
200'
Lower Temperature Dependence/
Higher Critical Temperature Layer
(Multilayer/Alloy)
210
Toward NM
Spacer Layer
Coupling Layer 220
Higher Temperature Dependence/
Lower Critical Temperature Layer
(Multilayer/Alloy)
230
z
x

FIG. 10

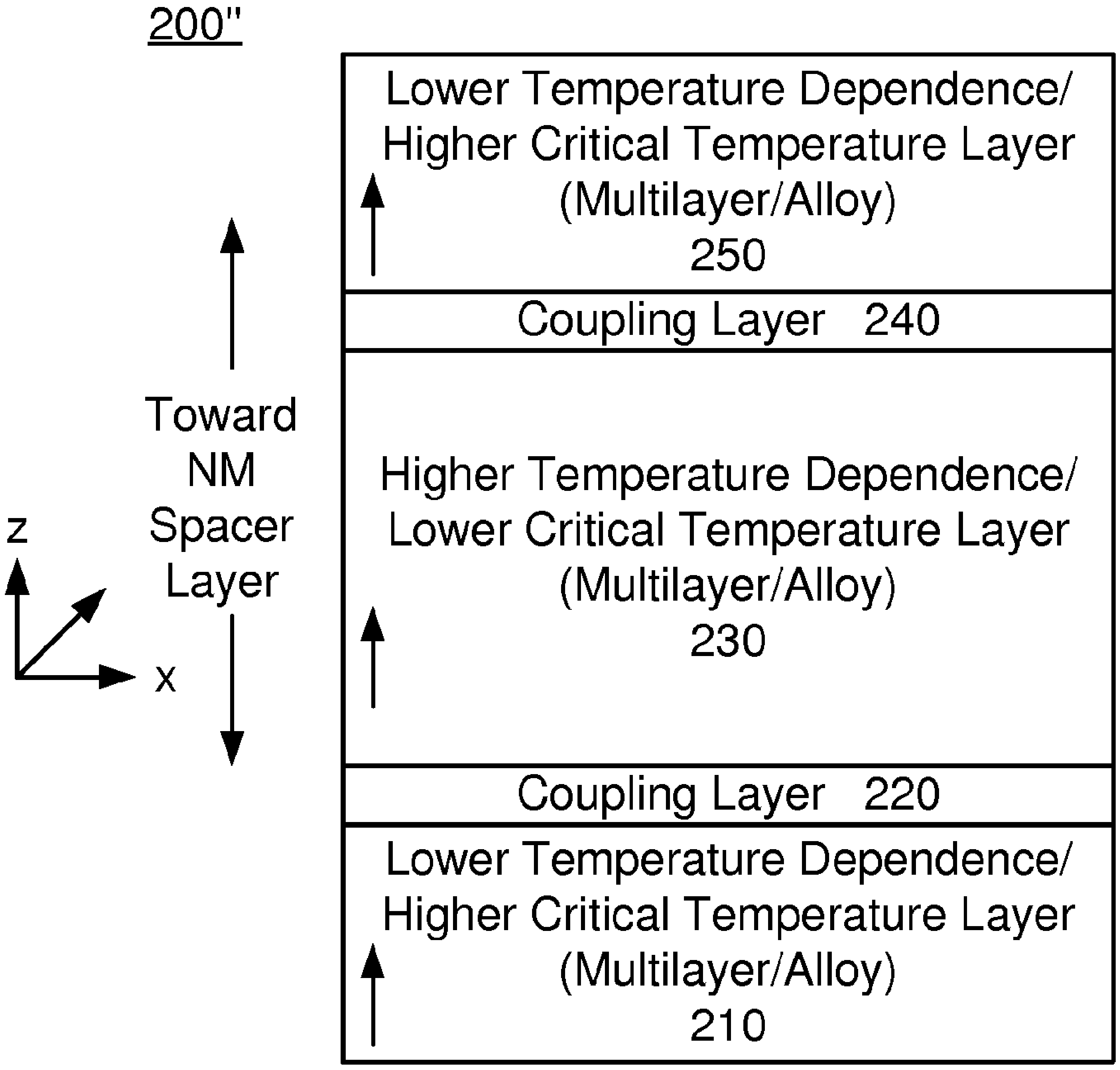
200"
Lower Temperature Dependence/
Higher Critical Temperature Layer
(Multilayer/Alloy)
250
Coupling Layer 240
Toward
NM
Spacer
Layer
Higher Temperature Dependence/
Lower Critical Temperature Layer
(Multilayer/Alloy)
230
z
x
Coupling Layer 220
Lower Temperature Dependence/
Higher Critical Temperature Layer
(Multilayer/Alloy)
210

FIG. 11

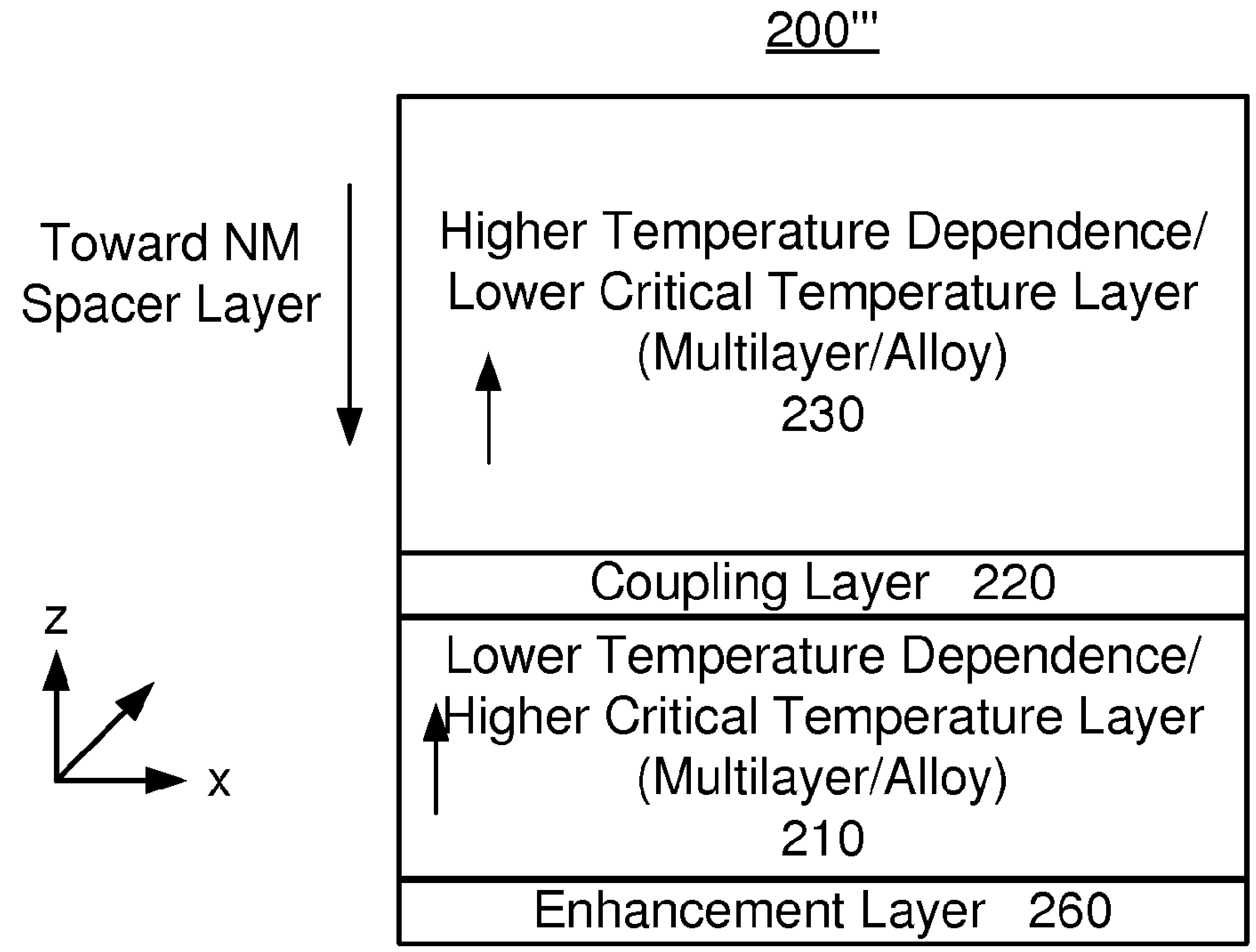
200'''
Toward NM Spacer Layer
Higher Temperature Dependence/ Lower Critical Temperature Layer (Multilayer/Alloy) 230
Coupling Layer 220
Lower Temperature Dependence/ Higher Critical Temperature Layer (Multilayer/Alloy) 210
Enhancement Layer 260
z
x

FIG. 12

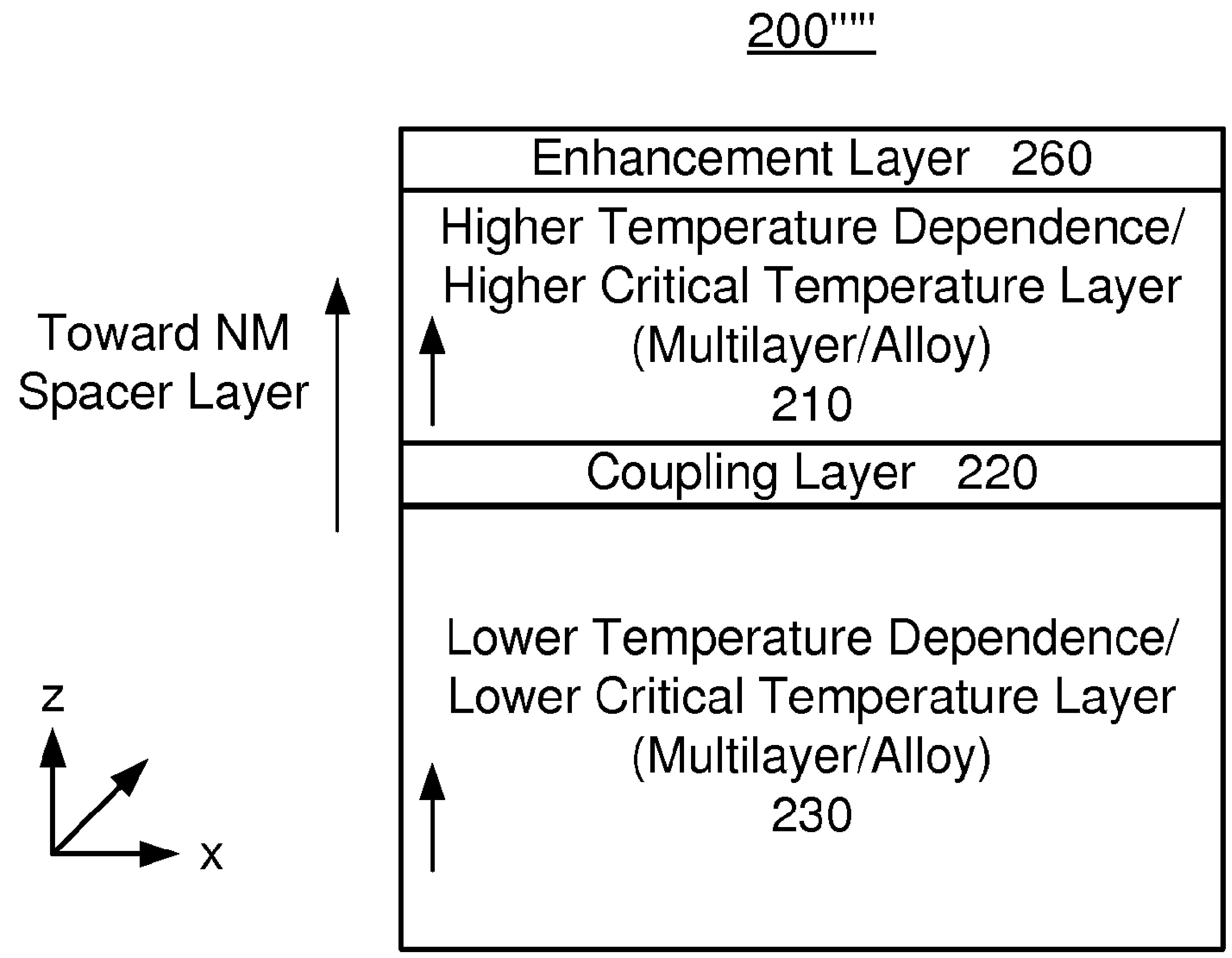
200''''
Enhancement Layer 260
Higher Temperature Dependence/ Higher Critical Temperature Layer (Multilayer/Alloy) 210
Toward NM Spacer Layer
Coupling Layer 220
Lower Temperature Dependence/ Lower Critical Temperature Layer (Multilayer/Alloy) 230
z
x

FIG. 13

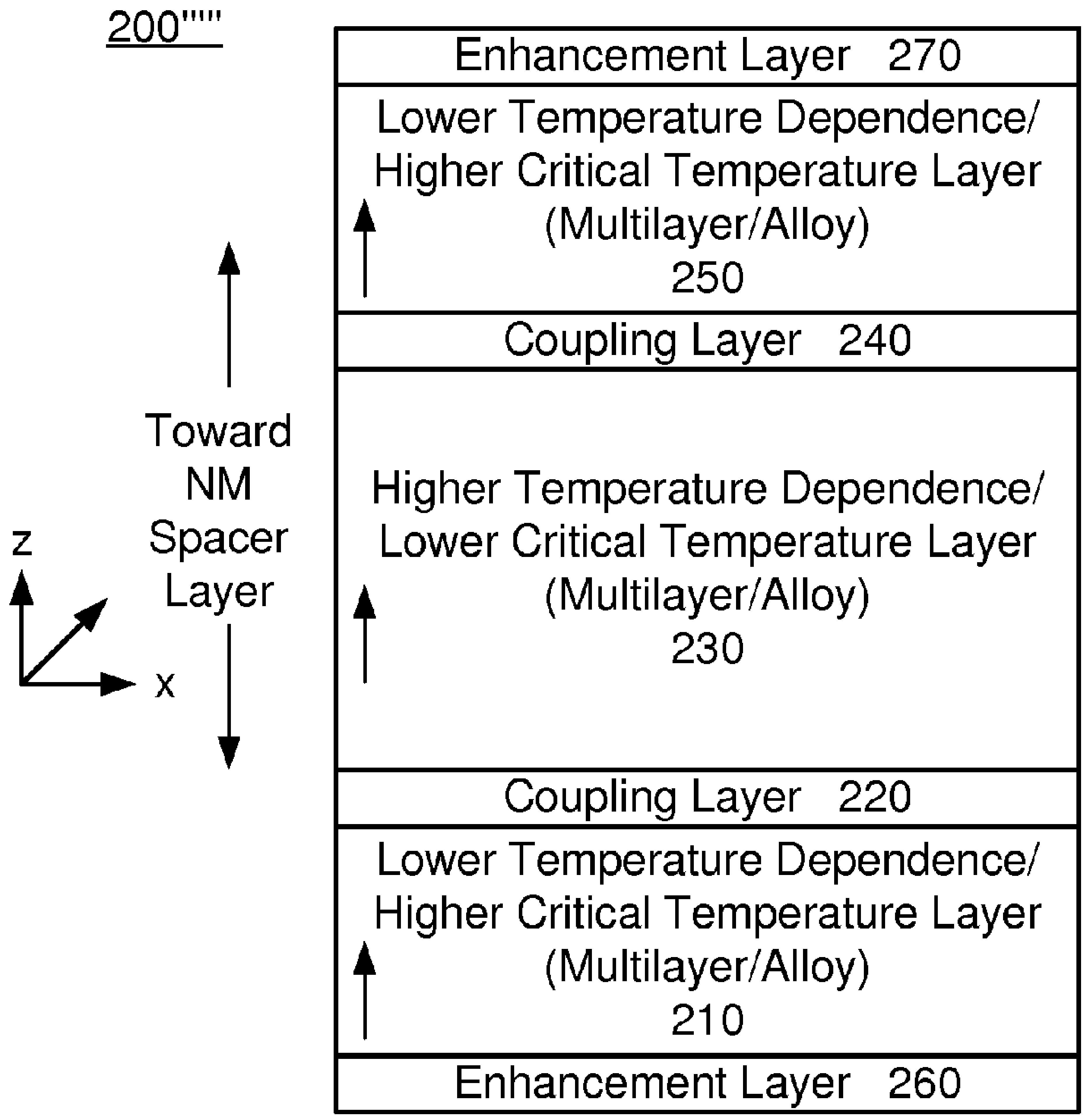
200'''''
Enhancement Layer 270
Lower Temperature Dependence/ Higher Critical Temperature Layer (Multilayer/Alloy) 250
Coupling Layer 240
Toward NM Spacer Layer
z
x
Higher Temperature Dependence/ Lower Critical Temperature Layer (Multilayer/Alloy) 230
Coupling Layer 220
Lower Temperature Dependence/ Higher Critical Temperature Layer (Multilayer/Alloy) 210
Enhancement Layer 260

FIG. 14

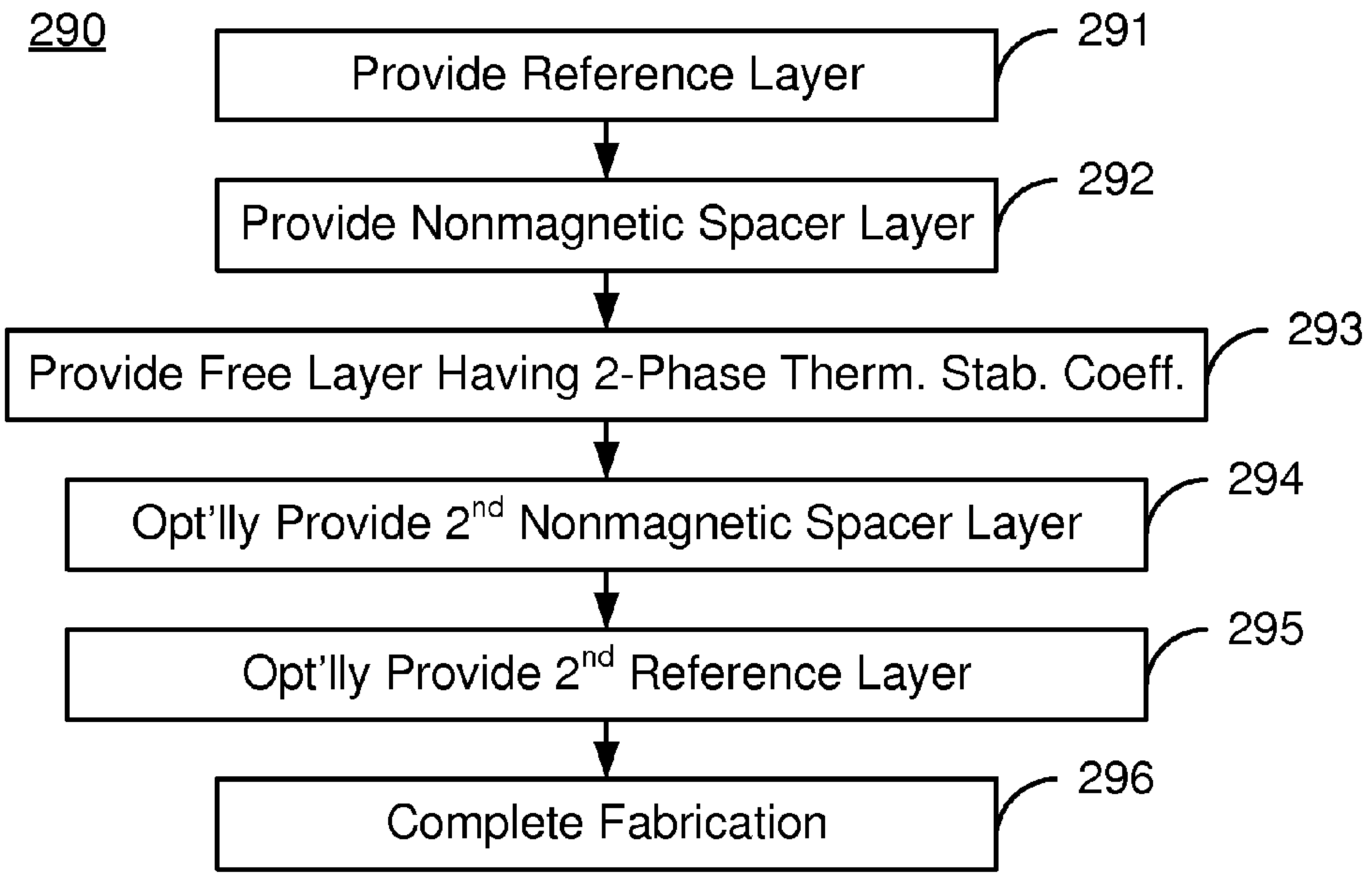
290
Provide Reference Layer
291
Provide Nonmagnetic Spacer Layer
292
Provide Free Layer Having 2-Phase Therm. Stab. Coeff.
293
Opt'lly Provide 2nd Nonmagnetic Spacer Layer
294
Opt'lly Provide 2nd Reference Layer
295
Complete Fabrication
296

FIG. 15

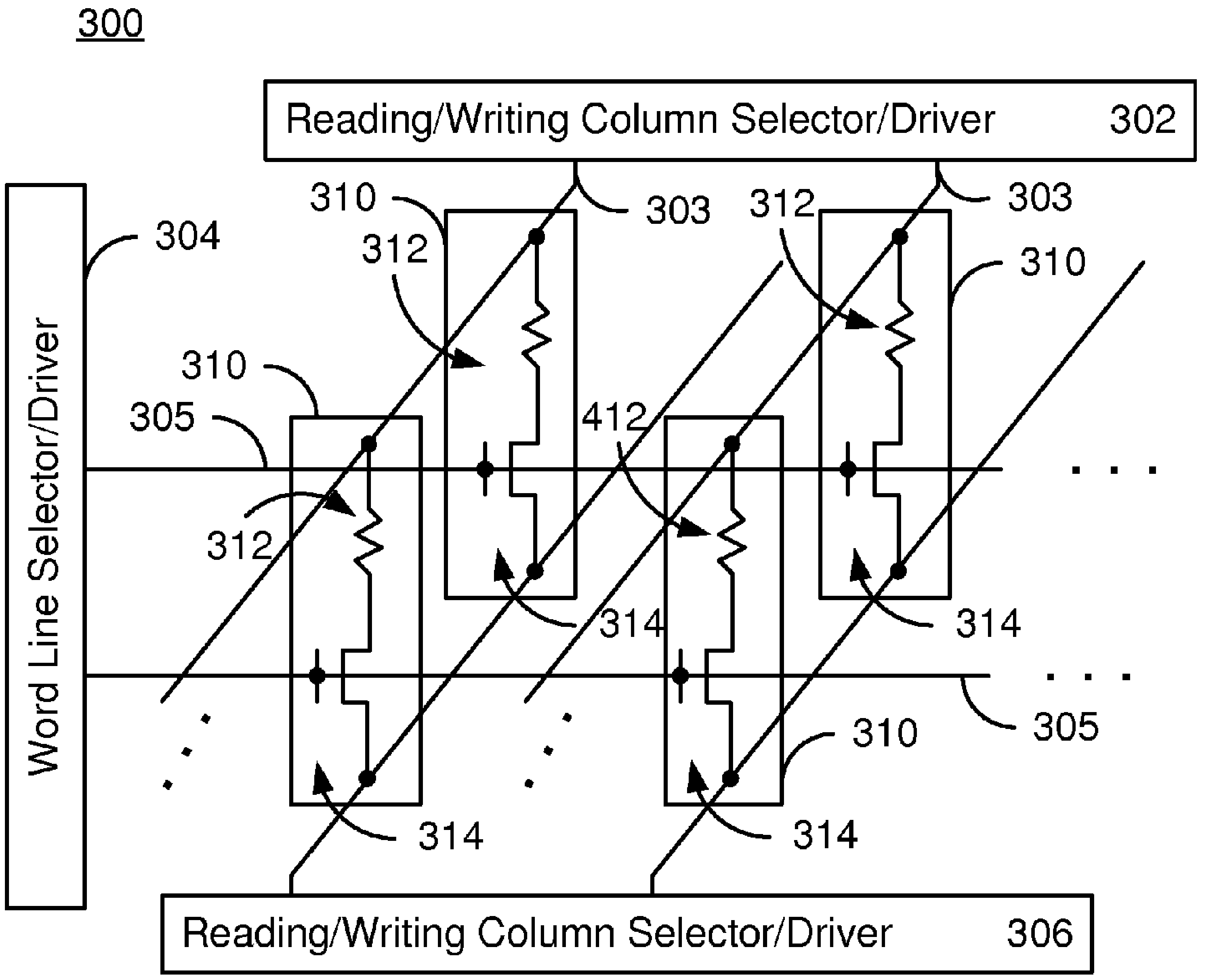

FIG. 16

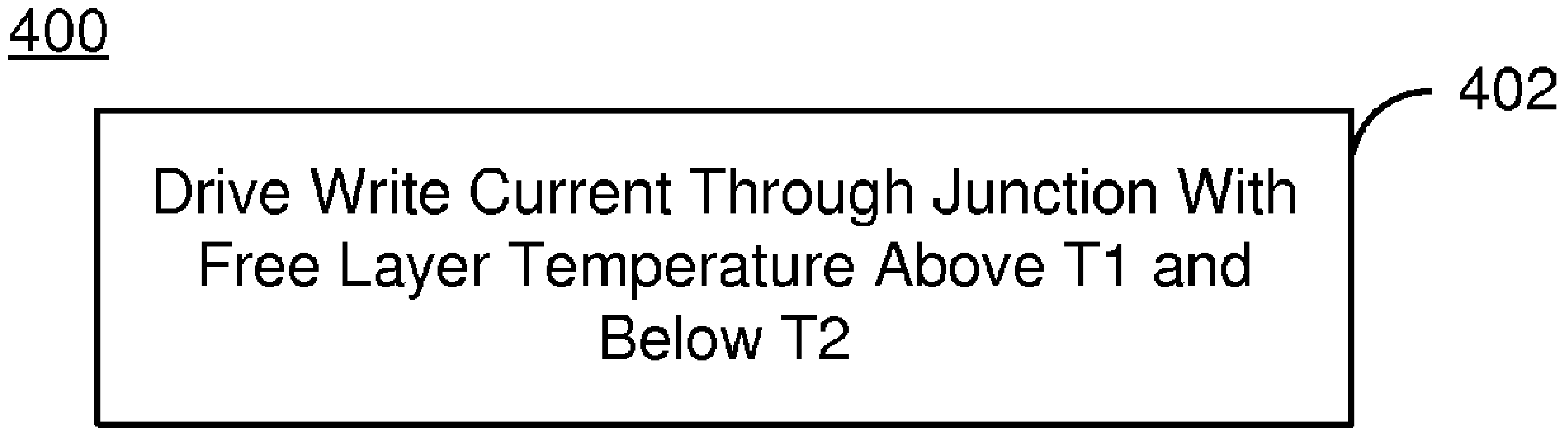

FIG. 17

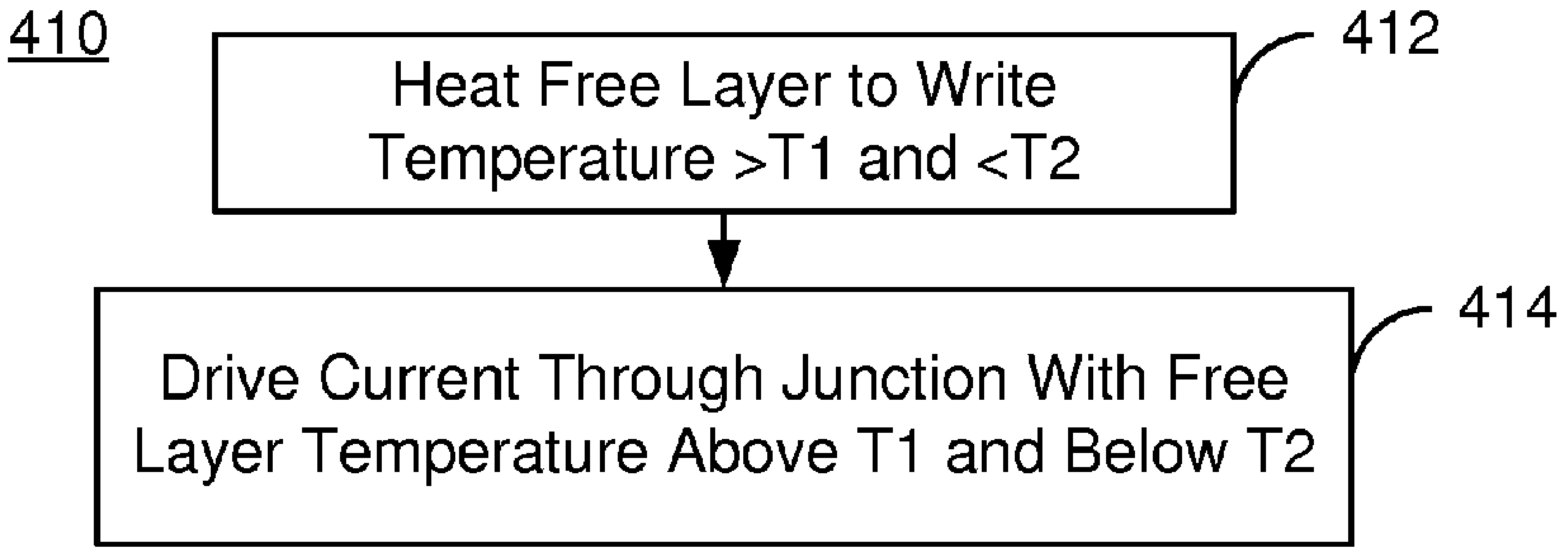

FIG. 18

METHOD AND SYSTEM FOR PROVIDING THERMALLY ASSISTED MAGNETIC JUNCTIONS HAVING A MULTI-PHASE OPERATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of provisional Patent Application Ser. No. 61/978,150, filed Apr. 10, 2014, entitled THERMAL ASSIST MAGNETIC TUNNEL JUNCTION WITH TWO PHASE OPERATION, assigned to the assignee of the present application, and incorporated herein by reference.

BACKGROUND OF THE INVENTION

Magnetic memories, particularly magnetic random access memories (MRAMs), have drawn increasing interest due to their potential for high read/write speed, excellent endurance, non-volatility and low power consumption during operation. An MRAM can store information utilizing magnetic materials as an information recording medium. One type of MRAM is a spin transfer torque random access memory (STT-MRAM). STT-MRAM utilizes magnetic junctions written at least in part by a current driven through the magnetic junction. A spin polarized current driven through the magnetic junction exerts a spin torque on the magnetic moments in the magnetic junction. As a result, layer(s) having magnetic moments that are responsive to the spin torque may be switched to a desired state.

For example, FIG. **1** depicts a conventional magnetic tunneling junction (MTJ) **10** as it may be used in a conventional STT-MRAM. The conventional MTJ **10** typically resides on a bottom contact **11**, uses conventional seed layer(s) **12** and includes a conventional antiferromagnetic (AFM) layer **14**, a conventional pinned layer **16**, a conventional tunneling barrier layer **18**, a conventional free layer **20**, and a conventional capping layer **22**. Also shown is top contact **24**.

Conventional contacts **11** and **24** are used in driving the current in a current-perpendicular-to-plane (CPP) direction, or along the z-axis as shown in FIG. **1**. The conventional seed layer(s) **12** are typically utilized to aid in the growth of subsequent layers, such as the AFM layer **14**, having a desired crystal structure. The conventional tunneling barrier layer **18** is nonmagnetic and is, for example, a thin insulator such as MgO. Alternatively, a conductive layer maybe used instead of the conventional tunneling barrier layer **18**.

The conventional pinned layer **16** and the conventional free layer **20** are magnetic. The magnetization **17** of the conventional pinned layer **16** is fixed, or pinned, in a particular direction, typically by an exchange-bias interaction with the AFM layer **14**. Further, other versions of the conventional MTJ **10** might include an additional pinned layer (not shown) separated from the free layer **20** by an additional nonmagnetic barrier or conductive layer (not shown).

The conventional free layer **20** has a changeable magnetization **21**. To switch the magnetization **21** of the conventional free layer **20**, a current is driven perpendicular to plane (in the z-direction). When a sufficient current is driven from the top contact **24** to the bottom contact **11**, the magnetization **21** of the conventional free layer **20** may switch to be parallel to the magnetization **17** of the conventional pinned layer **16**. When a sufficient current is driven from the bottom contact **11** to the top contact **24**, the magnetization **21** of the free layer may switch to be antiparallel to that of the pinned layer **16**. The differences in magnetic configurations correspond to different magnetoresistances and thus different logical states (e.g. a logical "0" and a logical "1") of the conventional MTJ **10**.

Because of their potential for use in a variety of applications, research in magnetic memories is ongoing. For example, mechanisms for improving the performance of STT-MRAM are desired. Accordingly, what is needed is a method and system that may improve the performance of the spin transfer torque based memories. The method and system described herein address such a need.

BRIEF SUMMARY OF THE INVENTION

A method and system for providing a magnetic junction usable in an electronic device are described. The magnetic junction includes at least one reference layer, at least one nonmagnetic spacer layer and a free layer. The nonmagnetic spacer layer(s) are between the reference layer(s) and the free layer. The free layer has a magnetic thermal stability coefficient Δ having a plurality of magnetic thermal stability coefficient phases. A first phase magnetic thermal stability coefficient has a first slope below a first temperature. A second phase magnetic thermal stability coefficient has a second slope above the first temperature and below a second temperature greater than the first temperature. The first slope and second slope unequal at the first temperature. The magnetic thermal stability coefficient is zero above the second temperature and greater than zero below the second temperature. The free layer is switchable between stable magnetic states when a write current is passed through the magnetic junction.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** depicts a conventional magnetic junction.

FIG. **2** depicts an exemplary embodiment of a magnetic junction usable in a magnetic memory programmable using spin transfer torque and which includes a free layer having a multi-phase magnetic thermal stability coefficient.

FIGS. **3**A and **3**B are graphs depicting embodiments of magnetic thermal stability coefficient versus temperature and versus time for a write operation.

FIG. **4** depicts another exemplary embodiment of a magnetic junction usable in a magnetic memory programmable using spin transfer torque and which includes a free layer having a multi-phase thermal stability coefficient.

FIG. **5** depicts another exemplary embodiment of a magnetic junction usable in a magnetic memory programmable using spin transfer torque and which includes a free layer having a multi-phase thermal stability coefficient.

FIG. **6** depicts another exemplary embodiment of a magnetic junction usable in a magnetic memory programmable using spin transfer torque and which includes a free layer having a multi-phase thermal stability coefficient.

FIG. **7** depicts another exemplary embodiment of a magnetic junction usable in a magnetic memory programmable using spin transfer torque and which includes a free layer having a multi-phase thermal stability coefficient.

FIG. **8** depicts an exemplary embodiment of a free layer having a multi-phase thermal stability coefficient and which may be programmed using spin transfer torque.

FIG. **9** is a graph depicting an exemplary embodiment of the magnetic thermal stability versus temperature constant for a free layer having a multi-phase magnetic thermal stability coefficient.

FIG. **10** depicts another exemplary embodiment of a free layer having a multi-phase thermal stability coefficient and which may be programmed using spin transfer torque.

FIG. **11** depicts another exemplary embodiment of a free layer having a multi-phase thermal stability coefficient and which may be programmed using spin transfer torque.

FIG. **12** depicts another exemplary embodiment of a free layer having a multi-phase thermal stability coefficient and which may be programmed using spin transfer torque.

FIG. **13** depicts another exemplary embodiment of a free layer having a multi-phase thermal stability coefficient and which may be programmed using spin transfer torque.

FIG. **14** depicts another exemplary embodiment of a free layer having a multi-phase thermal stability coefficient and which may be programmed using spin transfer torque.

FIG. **15** is a flow chart depicting an exemplary embodiment of a method for providing a magnetic junction usable in an electronic device programmable using spin transfer torque and for which the free layer has a multi-phase magnetic thermal stability coefficient.

FIG. **16** depicts an exemplary embodiment of a memory utilizing magnetic junctions in the memory element(s) of the storage cell(s).

FIG. **17** depicts an exemplary embodiment of a method for programming a magnetic junction usable in an electronic device programmable using spin transfer torque and for which the free layer has a multi-phase magnetic thermal stability coefficient.

FIG. **18** depicts an exemplary embodiment of a method for programming a magnetic junction usable in an electronic device programmable using spin transfer torque and for which the free layer has a multi-phase magnetic thermal stability coefficient.

DETAILED DESCRIPTION OF THE INVENTION

The exemplary embodiments relate to magnetic junctions usable in electronic devices, such as those using magnetic memories, and other devices using such magnetic junctions. The following description is presented to enable one of ordinary skill in the art to make and use the invention and is provided in the context of a patent application and its requirements. Various modifications to the exemplary embodiments and the generic principles and features described herein will be readily apparent. The exemplary embodiments are mainly described in terms of particular methods and systems provided in particular implementations. However, the methods and systems will operate effectively in other implementations. Phrases such as "exemplary embodiment", "one embodiment" and "another embodiment" may refer to the same or different embodiments as well as to multiple embodiments. The embodiments will be described with respect to systems and/or devices having certain components. However, the systems and/or devices may include more or less components than those shown, and variations in the arrangement and type of the components may be made without departing from the scope of the invention. The exemplary embodiments will also be described in the context of particular methods having certain steps. However, the method and system operate effectively for other methods having different and/or additional steps and steps in different orders that are not inconsistent with the exemplary embodiments. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features described herein.

The exemplary embodiments include magnetic junction(s) usable in magnetic device(s). For example, the magnetic junction(s) may be within magnetic storage cells for a magnetic memory programmable using spin transfer torque. The magnetic memories may be usable in electronic devices that make use of nonvolatile storage. Such electronic devices include but are not limited to cellular phones, tablets, and other mobile computing devices. A method and system for providing a magnetic junction usable in an electronic device are described. The magnetic junction includes at least one reference layer, at least one nonmagnetic spacer layer and a free layer. The nonmagnetic spacer layer(s) are between the reference layer(s) and the free layer. The free layer has a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases. A first phase magnetic thermal stability coefficient has a first slope below a first temperature. A second phase magnetic thermal stability coefficient has a second slope above the first temperature and below a second temperature greater than the first temperature. In some embodiments, at least a portion of the first slope is more negative than at least a portion of the second slope. The first slope and second slope unequal at the first temperature. The magnetic thermal stability coefficient is zero above the second temperature and greater than zero below the second temperature. The free layer is switchable between stable magnetic states when a write current is passed through the magnetic junction.

The exemplary embodiments are described in the context of particular magnetic junctions and magnetic memories having certain components. One of ordinary skill in the art will readily recognize that the present invention is consistent with the use of magnetic junctions and magnetic memories having other and/or additional components and/or other features not inconsistent with the present invention. The method and system are also described in the context of current understanding of the spin transfer phenomenon, of magnetic anisotropy, and other physical phenomenon. Consequently, one of ordinary skill in the art will readily recognize that theoretical explanations of the behavior of the method and system are made based upon this current understanding of spin transfer, magnetic anisotropy and other physical phenomena. However, the method and system described herein are not dependent upon a particular physical explanation. One of ordinary skill in the art will also readily recognize that the method and system are described in the context of a structure having a particular relationship to the substrate. However, one of ordinary skill in the art will readily recognize that the method and system are consistent with other structures. In addition, the method and system are described in the context of certain layers being synthetic and/or simple. However, one of ordinary skill in the art will readily recognize that the layers could have another structure. Furthermore, the method and system are described in the context of magnetic junctions and/or substructures having particular layers. However, one of ordinary skill in the art will readily recognize that magnetic junctions and/or substructures having additional and/or different layers not inconsistent with the method and system could also be used. Moreover, certain components are described as being magnetic, ferromagnetic, and ferrimagnetic. As used herein, the term magnetic could include ferromagnetic, ferrimagnetic or like structures. Thus, as used herein, the term "magnetic" or "ferromagnetic" includes, but is not limited to ferromagnets and ferrimagnets. The method and system are also described in the context of single magnetic junctions and substructures. However, one of ordinary skill in the art will readily recognize that the method and system are consistent with the use of magnetic memories having multiple magnetic junctions and using multiple substructures. Further, as used herein, "in-plane" is substantially within or parallel to the plane of one or more of the layers of a magnetic junction. Conversely, "perpendicular" corresponds to a direction that is substantially perpendicular to one or more of the layers of the magnetic junction.

FIG. **2** depicts an exemplary embodiment of a magnetic junction **100** as well as surrounding structures. For clarity, FIG. **2** is not to scale. The magnetic junction may be used in a magnetic device such as a spin transfer torque random access memory (STT-MRAM) and, therefore, in a variety of electronic devices. The magnetic junction **100** includes a reference layer **110**, a nonmagnetic spacer layer **120**, a free layer **130** and optional additional nonmagnetic spacer layer **140** and an optional additional reference layer **150**. The magnetic junction **100** may also include optional seed layer(s) **104**, optional pinning layer **106** for reference layer **110**, optional pinning layer **109** for optional reference layer **150** and optional capping layer(s) **108**. Also shown is an underlying substrate **101**, bottom contact **102** and optional top contact **103**. Devices including but not limited to a transistor may be formed in the substrate **101**. If the layers **140** and **150** are omitted, the magnetic junction **100** is a single magnetic junction. If layers **140** and **150** are included, the magnetic junction **100** is a dual magnetic junction. Although layers **110**, **120**, **130**, **140** and **150** are shown with a particular orientation with respect to the substrate **101**, this orientation may vary in other embodiments. For example, the reference layer **110** may be closer to the top (furthest from a substrate) of the magnetic junction **100**. In such an embodiment (in which layers **140**, **150** and **109** are also omitted), the magnetic junction **100** would be a bottom free layer junction. If the reference layer **110** is closest to the substrate **101** and layers **140**, **150** and **109** are omitted, the magnetic junction is a top free layer junction. The optional pinning layer(s) **106** and **109** may be used to fix the magnetization of the reference layer(s) **110** and **150**, respectively. In some embodiments, the optional pinning layers **106** and **109** may be AFM layers or multilayers that pin the magnetizations of the pinned layers **110** and **150**, respectively, by an exchange-bias interaction. However, in other embodiments, the optional pinning layers **106** and **109** may be omitted or another structure may be used. For example, if the perpendicular magnetic anisotropy energy of the reference layer **110** exceeds the out of plane demagnetization energy, the magnetic moment of the reference layer **110** may be out of plane (e.g. perpendicular-to-plane). This situation is shown in FIG. **2**. In such embodiments, the pinning layer **106** may be omitted. Similarly, the magnetic moment of the optional reference layer **150** may be out-of-plane (e.g. perpendicular-to-plane) of the perpendicular magnetic anisotropy energy of the layer **150** exceeds the out-of-plane demagnetization energy. The magnetic junction **100** is also configured to allow the free layer **130** to be switched between stable magnetic states when a write current is passed through the magnetic junction **100**. Thus, the free layer **130** is switchable utilizing spin transfer torque.

The reference layer **110** is magnetic and may have its magnetization pinned, or fixed, in a particular direction. Although depicted as a simple layer, the reference layer **110** may include multiple layers. For example, the reference layer **110** may be a SAF including magnetic layers antiferromagnetically or ferromagnetically coupled through thin layers, such as Ru. In such a SAF, multiple magnetic layers interleaved with thin layer(s) of Ru or other material may be used. The reference layer **110** may also be another multilayer. In the embodiment depicted in FIG. **2**, the reference layer **110** has a perpendicular anisotropy energy that exceeds the out-of-plane demagnetization energy. Thus, the reference layer **110** may have its magnetic moment oriented perpendicular-to-plane as shown. Other orientations of the magnetization of the reference layer **110** are possible. In other embodiments, for example, the magnetic moment of the reference layer **110** may be in-plane. The optional reference layer **150** is analogous to the reference layer **110**. Thus, the optional reference layer **150** is magnetic and may have its magnetization pinned, or fixed, in a particular direction. Although depicted as a simple layer, the optional reference layer **150** may include multiple layers. For example, the optional reference layer **150** may be a SAF or other multilayer. In the embodiment depicted in FIG. **2**, the optional reference layer **150** has a perpendicular anisotropy energy that exceeds the out-of-plane demagnetization energy. Thus, the optional reference layer **150** may have its magnetic moment oriented perpendicular-to-plane as shown. Other orientations of the magnetization of the optional reference layer **150** are possible. In other embodiments, for example, the magnetic moment of the optional reference layer **150** may be in-plane. There is no requirement that the reference layer **110** and the optional reference layer **150** be the same in a magnetic junction in which both are present.

The spacer layer **120** is nonmagnetic. In some embodiments, the spacer layer **120** is an insulator, for example a tunneling barrier. In such embodiments, the spacer layer **120** may include crystalline MgO, which may enhance the TMR of the magnetic junction as well as the perpendicular magnetic anisotropy of the free layer **130**. In other embodiments, the spacer layer **120** may be a conductor, such as Cu. In alternate embodiments, the spacer layer **120** might have another structure, for example a granular layer including conductive channels in an insulating matrix. The optional spacer layer **140** is analogous to the spacer layer **120**. Thus, the optional spacer layer **140** is nonmagnetic and may be a tunneling barrier. In such embodiments, the spacer layer **120** may include crystalline MgO. In other embodiments, the spacer layer **120** may be a conductor, such as Cu. In alternate embodiments, the spacer layer **120** might have another structure, for example a granular layer including conductive channels in an insulating matrix. There is, however, no requirement that the spacer layers **120** and **140** be the same if both are present in the magnetic junction **100**.

The free layer **130** is magnetic and is written using a current driven through the magnetic junction **100**. In some embodiments, the free layer **130** is a multilayer. For example, the free layer **130** maybe a SAF and/or may include multiple adjoining ferromagnetic layers that are exchange coupled. Other multilayers may also be used. The layers in the multilayer may be single elements, alloys, and may include nonmagnetic layers. In other embodiments, the free layer **130** may be a single layer. In the embodiment depicted in FIG. **2**, the free layer **130** has a perpendicular anisotropy energy that exceeds the out-of-plane demagnetization energy. Thus, the free layer **130** may have its magnetic moment oriented perpendicular-to-plane as shown. Because this magnetic moment is switchable, it is depicted as a dual headed arrow in FIG. **2**. In other embodiments, other directions are possible for the magnetic moment of the free layer **130**. For example, the free layer **130** may have its magnetic moment stable in-plane or at an angle from the z-direction.

The free layer **130** is thermally stable when the magnetic junction **100** is not being written (quiescent/in standby mode). The free layer **130** is also characterized by a magnetic thermal stability coefficient, Δ. In some embodiments, therefore, the magnetic thermal stability coefficient, Δ, of the free layer **130** is at least sixty at non-programming operating temperatures, or standby temperatures. In some such embodiments, the magnetic thermal stability coefficient is at least eighty up to a preselected standby temperature. This standby temperature is above room temperature. In some embodiments, this standby temperature is at least eighty-five degrees Celsius. During writing, however, the free layer **130** is heated. This heating may be accomplished using only the write current driven through the magnetic junction **100** or by using the write current in combination with another heat source. The magnetic thermal stability coefficient, Δ, of the free layer **130** decreases with increasing temperature. Thus, the magnetic thermal stability coefficient of the free layer **130** is below eighty during writing. In some embodiments, the magnetic thermal stability coefficient of the free layer **130** is desired to be not more than forty during writing. Thus, the free layer **130** may be written at temperatures on the order of one-hundred fifty degrees Celsius or higher. However, the magnetic thermal stability coefficient of the free layer **130** is also desired to be above zero during writing. In some embodiments, the magnetic thermal stability coefficient is desired to be at least twenty at temperature achieved during writing. In some embodiments, the magnetic thermal stability coefficient is at least twenty and not more than twenty-five during at least a portion of the write operation. Thus, in some embodiments, the free layer temperature does not exceed two hundred and forty degrees Celsius during writing. However, other standby temperatures, minimum write temperatures and maximum write temperatures may be employed.

The free layer **130** also has a multi-phase magnetic thermal stability coefficient, $\Delta = K_u * V/k_B T$, where $K_u V$ is an expression for the (temperature dependent) energy barrier for switching of the magnetic moment, k_b is the Boltzman constant and T is temperature in Kelvin. As used herein a multi-phase magnetic thermal stability coefficient has multiple phases for which the magnetic thermal stability coefficient is greater than zero. The magnetic thermal stability coefficient may also be zero above a particular critical temperature. However, this portion of the magnetic thermal stability coefficient is not considered to be part of the multi-phase behavior. Different phases are separated by phase transition(s). The slopes of the phases of the magnetic thermal coefficient differ at the temperature corresponding to the phase transition. If the magnetic thermal stability coefficient has a first phase below a first temperature and a second phase above the first (phase transition) temperature, the first temperature is a phase transition temperature. The slopes of the first and second phases are not equal at the first temperature (the phase transition temperature). In other words, the (first) slope of the magnetic thermal stability coefficient (for the first phase) just below the first temperature is different from the (second) slope of the magnetic thermal stability coefficient (for the second phase) just above the first temperature. The slope of the magnetic thermal stability coefficient may thus be considered to be discontinuous at this temperature. Stated differently, the magnetic thermal stability coefficient has a sharp transition between the first and second phases. The magnetic thermal stability coefficient may include more than two phases. For example, the magnetic thermal stability coefficient might include three or more phases. Different phases are separated by phase transitions analogous to that described above and have magnitudes greater than zero. In addition to having multiple phases, the slopes (magnitude of A versus temperature) of a

first phase and a second phase differ. At least a portion of the slope of the first phase is more negative than at least a portion of the slope of the second phase. The slope of the first phase generally has a larger magnitude than the slope of the second phase. In some embodiments, this means that the total change in the magnetic thermal stability constant for the first phase from room temperature to the phase transition temperature divided by the change in temperature (total change in Δ for phase 1/(phase transition temperature–room temperature)) is greater than the total change in the magnetic thermal stability constant for the second phase from the first phase transition temperature to the second phase transition temperature or critical temperature divided by the change in temperature for the over the second phase (total change in Δ for phase 2/(phase transition temperature or critical temperature–room temperature)). In other words, the magnetic thermal stability coefficient changes more rapidly for the first phase than for the second phase.

For example, FIGS. **3**A and **3**B are graphs depicting the magnetic thermal stability coefficient behavior for the free layer **130**. Referring to FIGS. **2**-**3**B, although particular slopes and shapes are shown in FIGS. **3**A-**3**B, these are explanatory purposes only and are not meant to represent specific numerical values except where noted. FIG. **3**A includes a curve **160** depicting the magnetic thermal stability coefficient versus temperature of the free layer **130**. For comparison, a dashed curve **170** depicting a conventional magnetic thermal stability coefficient is also shown. As can be seen in FIG. **3**A, the conventional magnetic thermal stability coefficient **170** smoothly goes to zero, with an increasingly negative slope. At temperature T_1, the conventional magnetic thermal stability coefficient **170** goes to zero and remains zero above T_1. Thus, the conventional magnetic thermal stability coefficient **170** has a single phase below the critical temperature, T_1.

In contrast, the magnetic thermal stability coefficient **160** includes two phases **162** and **164**. The magnetic thermal stability coefficient **160** goes to zero at T_2 and may remain zero above T_2. Thus, T_2 may be considered the critical temperature for the magnetic thermal stability coefficient **160**. The magnetic thermal stability coefficient **160** is greater than zero below T_2 and has a phase transition at T_1. The first phase **162** is for temperatures below T_1, while the second phase **164** is for temperatures between T_1 and T_2. At the transition between the phases **162** and **164**, the slope of the magnetic thermal stability coefficient **160** is discontinuous. The slope of the first phase **162** and the slope of the second phase **164** differ at the transition temperature T_1. Stated differently, the slope of the magnetic thermal stability coefficient **160** for the first phase **162** just below the temperature T_1 is different from the slope of the magnetic thermal stability coefficient **160** for the second phase **164** just above the temperature T_1. In other words, the magnetic thermal stability coefficient **160** has a sharp (phase) transition at T_1. Below T_1, the first phase **162** of the magnetic thermal stability coefficient **160** may change more rapidly. Above T_1, the second phase **164** of the magnetic thermal stability coefficient **160** may change more slowly. Thus, the slope of the first phase **162** is generally more negative than the slope of the second phase **164**. In some embodiments, this corresponds to: $|\Delta_{T1}-\Delta_0|/(T_1-T_0)>|\Delta_{T2}-\Delta_{T1}|/(T_2-T_1)$. Because the second phase **164** of the magnetic thermal stability coefficient **160** changes more slowly than the first phase, the difference between T_1 and T_2 may be significant. In some embodiments, T_2 is at least one hundred degrees Celsius higher than T_1. For example, T_1 may be approximately one hundred fifty degrees Celsius and not more than two hundred degrees Celsius. In such an embodiment, T_2 may be two hundred fifty degrees Celsius or greater. In some such embodiments, T2 may be as high as eight hundred degrees Celsius.

As can be seen in FIG. **3**A, the magnetic thermal stability coefficients **160** and **170** are both above a minimum desired thermal stability coefficient for standby, Δ_s, as long as the temperature does not exceed T_s. T_s is the maximum temperature at which the free layer **130** is expected to be in standby (quiescent). In some embodiments, T_s is not more than eighty-five degrees Celsius. The minimum desired magnetic thermal stability coefficient or standby (Δ_s) is described above and may be eighty in some embodiments. Thus, the free layer **130** is sufficiently stable for the magnetic junction **100** to be used in STT-MRAM.

The magnetic junction **100** is heated during writing. The desired temperatures and range for the magnetic thermal stability coefficient **160** for programming are also indicated in FIG. **3**A. Programming may be achieved at temperatures of at least T_{w1} and not more than T_{w2}. In the embodiment shown, T_{w1} and T_1 are different. In other embodiments, T_1 and T_{w1} may be the same. These temperatures correspond to a desired range for the magnetic thermal stability coefficient **160** of at least twenty and, in some embodiments, not more than forty. In some such embodiments, the magnetic thermal stability coefficient is not more than twenty-five for temperatures not less than T_{w1} and not more than T_{w2}. In some embodiments, this range is approximately ninety degrees Celsius. For example, T_{w1} may be at least one hundred and fifty degrees Celsius, while T_{w2} may be not more than two hundred forty degrees Celsius. This range arises from the undefined standby temperature of the device. Thus, if the device is cooler, for example at 0 C during the start of the writing cycle, it may heat up to 150 C, whereas if the starting temperature is 80 C, it will heat up to 230 C or so. However, other temperature ranges are possible. In general the desired temperature range for writing corresponds to a reduced magnetic thermal stability coefficient **160**, which translates to a lower write current. Further, in the desired temperature range for writing, the magnetic thermal stability coefficient is greater than zero. As discussed below, this may translate to reduced write errors.

For a read operation, a read current may be driven through the magnetic junction **100** and the state determined based on magnetoresistance. The minimum magnetic thermal stability coefficient for standby (Δ_s) is selected such that the free layer **130**, and thus the magnetic junction **100**, remain stable during a write operation. This may correspond to the temperature of the free layer **130** not exceeding T_s during reading. Thus, a read operation generally does not change the state of the magnetic junction **100**.

In a write operation, a write current is driven through the magnetic junction **100** in the current perpendicular-to-plane (CPP) configuration to program the magnetic junction **100**. In FIG. **2**, the write current is driven between the contacts **101** and **103**, substantially in the z-direction. The write current alone or in addition to heat from another source heats the free layer **130**. In some embodiments, an additional line or heater (not shown in FIG. **2**) is used to heat the magnetic junction **100** being programmed. The magnetic junction **100** is programmed using at least thermally assisted spin transfer. Other mechanisms, such as an external magnetic field and/or a spin orbit coupling, might also be employed.

FIG. **3**B includes a curve **180** depicting the magnetic thermal stability coefficient for the magnetic junction **100** versus time during a write operation. For comparison, the dashed line **190** indicates the behavior off a conventional magnetic junction during a thermally assisted write operation. The write current pulse or other heating mechanism is assumed to be switched off at time t_s. For a conventional magnetic junction, the free layer is heated above the critical temperature, resulting in the conventional magnetic thermal stability coefficient **190** reaching zero. Spin transfer is used to switch the magnetic moment of the conventional free layer and the heat turned off. For some time after t_s, the conventional magnetic thermal stability coefficient **190** remains zero. Only when enough time has passed for the conventional free layer to have sufficiently cooled does the magnetic thermal stability coefficient **190** increase. At times when the conventional magnetic thermal stability coefficient **190** is low, the conventional free layer magnetic moment is unstable and may switch, resulting in a write error.

In contrast, the curve **180** indicates the magnetic thermal stability coefficient of the free layer **130** during writing. As heat is applied, either externally or via a write current, the magnetic thermal stability coefficient **180** decreases and passes from the first phase **182** to the second phase **184**. The free layer **130** reaches the transition temperature, T_1, at time t_1. The magnetic thermal stability coefficient **180** remains in the second phase **184** and continues to decrease at a smaller rate as time passes and the free layer **130** continues increase in temperature. At time t_s, the write current or heater power is turned off. The free layer **130** has been written by time t_s. In other embodiments, heating may be terminated at a different time than the write current. However, these times are generally desired to be very close, for example within a few hundred nanoseconds. During writing, between times t_1 and t_s, the magnetic thermal stability coefficient is at least Δ_{w2} and not more than Δ_{w1}. Δ_{w2} is greater than zero. In some embodiments, Δ_{w2} is at least twenty and Δ_{w1} is not more than forty. In some such embodiments, Δ_{w2} is at least twenty and Δ_{w1} is not more than twenty-five. After time t_s, the free layer **130** begins to cool. At time t_3, the free layer **130** has cooled sufficiently to transition back to the first phase **182**. As can be seen in FIGS. **3**A and **3**B, the first phase **162**/**182** of the magnetic thermal stability coefficient **160**/**180** changes more rapidly with temperature, and thus time, than the second phase **164**/**184**. Because the magnetic thermal stability coefficient **160**/**180** is greater than zero during the write operation and remains above zero, the free layer magnetic moment is more likely to remain stable after being written.

The multi-phase nature of the magnetic thermal stability coefficient of the free layer **130** may be achieved by configuring the free layer **130**. For example, the perpendicular magnetic anisotropy of the free layer **130** may be engineered to have multiple dependencies. For example, the free layer **130** may be a multilayer. One subset of sublayer(s) in the multilayer may have a perpendicular anisotropy that is insensitive or substantially less sensitive to temperature. For example, one or more of the sublayers may have a perpendicular anisotropy that arises primarily from a bulk interaction, such as crystalline structure or internal strain. This subset has a perpendicular anisotropy that is generally relatively insensitive to temperature and may correspond to at least the second phase of the magnetic thermal stability coefficient. Another subset of sublayer(s) may have a perpendicular anisotropy that is due primarily to an interface-induced anisotropy. Such a magnetic anisotropy is generally more sensitive to temperature. Consequently, the magnetic thermal stability coefficient may also be more sensitive to temperature. This subset of sublayer(s) form at least the first phase of the magnetic thermal stability coefficient. Other subset(s) of sublayer(s) may correspond to other phase(s) of the magnetic thermal stability coefficient for the free layer

130 having different temperature sensitivities. For example, the free layer **130** may include a first layer having an interface induced perpendicular anisotropy and a second layer having a bulk perpendicular magnetic anisotropy. These layers may be magnetically coupled through a coupling layer. Such a free layer **130** has at least two phases for the magnetic thermal stability coefficient **160/180** as discussed above. In another embodiment, the free layer **130** may include multiple sublattices. One sublattice may correspond to the second phase and a magnetic thermal stability coefficient that is less sensitive to temperature. This sublattice may also have a bulk anisotropy that gives rise to the magnetic thermal stability coefficient. Another sublattice may correspond to the first phase and a magnetic thermal stability coefficient that is more sensitive to temperature. This sublattice may have an interfacial perpendicular anisotropy. Additional sublattice(s) may correspond to other phases having different temperature sensitivities of the magnetic thermal stability coefficient to temperature. For example, the free layer **130** may include an alloy having a first sublattice having a perpendicular magnetic anisotropy with a strong temperature dependence and a second sublattice having a perpendicular magnetic anisotropy with a weaker temperature dependence. Such a free layer **130** has at least two phases for the magnetic thermal stability coefficient.

The magnetic junction **100** and free layer **130** may have improved performance. The free layer **130** may be switched using spin transfer torque. Thus, a more localized physical phenomenon may be used to write to the free layer **130**. The thermal properties of the free layer **130** and magnetic junction **100** may also be configured. In particular, the magnetic moment of the free layer **130** may be more easily and reliably switched. Because higher temperature switching may be used, the write current may be reduced and/or switching may be performed more rapidly. This switching may occur at a magnetic thermal stability coefficient that is greater than zero at least in part because of the multi-phase nature of the magnetic thermal stability constant. As a result, the free layer magnetic moment is more stable after switching, during cooling of the free layer **130**. Consequently, reliability of programming the free layer **130** may be enhanced. Thus, the magnetic junction **100** may have improved performance.

FIG. **4** depicts another exemplary embodiment of a magnetic junction **100'** usable in a magnetic device as well as surrounding structures. For clarity, FIG. **4** is not to scale. The magnetic junction **100'** may be used in a magnetic device such as a STT-MRAM and, therefore, in a variety of electronic devices. The magnetic junction **100'** is analogous to the magnetic junction **100**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100'** includes a reference layer **110**, a nonmagnetic spacer layer **120**, and a free layer **130** that are analogous to the layers **110**, **120** and **130**, respectively, for the magnetic junction **100**. Also shown are an underlying substrate **101**, optional seed layer **104**, optional pinning layer **106**, and optional capping layer **108** that are analogous to those depicted with the magnetic junction **100**. The layers **140**, **150** and **109** have been omitted. In addition, the pinning layer **106** is omitted. In the embodiment shown in FIG. **4**, therefore, the magnetic junction **100'** is a single magnetic junction including only one nonmagnetic spacer layer **120**. Although the free layer **130** is further from the substrate **101** than the reference layer **110** in the magnetic junction **100'**, in other embodiments, the order of the layers **110**, **120** and **130** may be reversed. Alternatively, the single magnetic junction **100** could include layers **130**, **140** and **150**.

The free layer **130** has multi-phase magnetic thermal stability constant analogous to that of the free layer **130** depicted in FIG. **2** and described above. In some embodiments, the magnetic thermal stability constant of the free layer **130** of FIG. **4**, may be analogous to the magnetic thermal stability constant **160/180** depicted in FIGS. **3**A and **3**B.

The free layer **130** is programmed and read in an analogous manner to the free layer **130** described above. Thus, the magnetic junction **100'** may remain stable during reading and may share the benefits of the magnetic junction **100**. The free layer **130** may be switched using spin transfer torque. Thus, a more localized physical phenomenon may be used to write to the free layer **130**. In particular, the magnetic moment of the free layer **130** may be more easily and reliably switched using thermal assistance. Because higher temperature switching may be used, the write current may be reduced and/or switching may be performed more rapidly. As described above, this switching may occur at a magnetic thermal stability coefficient that is greater than zero at least in part because of the multi-phase nature of the magnetic thermal stability constant. The free layer magnetic moment is more stable after switching, during cooling of the free layer **130**. Consequently, reliability of programming the free layer **130** may be enhanced. Thus, the magnetic junction **100'** may have improved performance.

FIG. **5** depicts another exemplary embodiment of a magnetic junction **100"** usable in a magnetic device as well as surrounding structures. For clarity, FIG. **5** is not to scale. The magnetic junction **100"** may be used in a magnetic device such as a STT-MRAM and, therefore, in a variety of electronic devices. The magnetic junction **100"** is analogous to the magnetic junctions **100** and **100'**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100"** includes a reference layer **110**, a nonmagnetic spacer layer **120**, a free layer **130**, an additional nonmagnetic spacer **140** and a reference layer **150** that are analogous to the layers **110**, **120**, **130**, **140** and **150** respectively, for the magnetic junctions **100** and **100'**. Also shown are an underlying substrate **101**, optional seed layer **104**, optional pinning layer **106**, and optional capping layer **108** that are analogous to those depicted with the magnetic junction **100**. The pinning layers **106** and **109** are omitted. In the embodiment shown in FIG. **5**, therefore, the magnetic junction **100"** is a dual magnetic junction. The magnetic moments of the reference layers **110** and **150** are shown in the dual (antiparallel) state. This state may be desired for writing. In other embodiments, the magnetic moments of the reference layer **110** and **150** may be parallel (antidual state), which may be more desirable for read operations. In other embodiments, the magnetic moments of the layers **110** and **150** may be switched between the dual and antidual states depending upon the operation to be performed.

The free layer **130** has multi-phase magnetic thermal stability constant analogous to that of the free layer **130** depicted in FIG. **2** and described above. In some embodiments, the magnetic thermal stability constant of the free layer **130** of FIG. **5**, may be analogous to the magnetic thermal stability constant **160/180** depicted in FIGS. **3**A and **3**B.

The free layer **130** of the magnetic junction **100"** is programmed and read in an analogous manner to the free layer **130** described above. Thus, the magnetic junction **100"** may remain stable during reading and may share the benefits of the magnetic junction **100** and **100'**. The free layer **130** may be switched using thermally assisted spin transfer torque. Thus, a more localized physical phenomenon may be used to write to the free layer **130**. Because higher temperature switching may be used, the write current may be reduced and/or switching may be performed more rapidly. As described above, this switching may occur at a magnetic thermal stability coefficient that is greater than zero at least in part because of the multi-phase nature of the magnetic thermal stability constant. The free layer magnetic moment is more stable after switching, during cooling of the free layer **130**. Consequently, reliability of programming the free layer **130** may be enhanced. Further, programming and/or reading may be enhanced by the presence of multiple reference layers **110** and **150**. Thus, the magnetic junction **100"** may have improved performance.

FIG. **6** depicts another exemplary embodiment of a magnetic junction **100'"** usable in a magnetic device as well as surrounding structures. For clarity, FIG. **6** is not to scale. The magnetic junction **100'"** may be used in a magnetic device such as a STT-MRAM and, therefore, in a variety of electronic devices. The magnetic junction **100'"** is analogous to the magnetic junctions **100**, **100'** and **100"**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100'"** includes a reference layer **110'**, a nonmagnetic spacer layer **120**, and a free layer **130** that are analogous to the layers **110**, **120** and **130**, respectively, for the magnetic junctions **100**, **100'** and **100"**. Other layers are not shown and/or have been omitted. For example, the layers **106**, **140**, **150** and **109** have been omitted. In the embodiment shown in FIG. **6**, therefore, the magnetic junction **100"** is a single magnetic junction including only one nonmagnetic spacer layer **120**. The free layer **130** shown on top of the reference layer **110'**. In other embodiments, the order of the layers **110'**, **120** and **130** may be reversed.

The free layer **130** has multi-phase magnetic thermal stability constant analogous to that of the free layer **130** depicted in FIG. **2** and described above. In some embodiments, the magnetic thermal stability constant of the free layer **130** of FIG. **6**, may be analogous to the magnetic thermal stability constant **160**/**180** depicted in FIGS. **3**A and **3**B.

The reference layer **110'** is a multilayer including ferromagnetic layers **112** and **116** separated by a nonmagnetic spacer layer **114**. In other embodiments, other multilayer(s) may be used for the reference layer **110'**. Further, each layer **112**, **114**, and **116** may include sublayers. In the embodiment shown, the reference layer **110'** is a SAF in which the magnetic moments of the ferromagnetic layers **112** and **116** are coupled antiparallel. In other embodiments, the magnetic moments of the layers **112** and **116** may be coupled in another manner.

The free layer **130** is programmed and read in an analogous manner to the free layer **130** described above. Thus, the magnetic junction **100'"** may remain stable during reading and may share the benefits of the magnetic junctions **100**, **100'** and **100"**. The free layer **130** may be switched using thermally assisted spin transfer torque. Thus, a more localized physical phenomenon may be used to write to the free layer **130**. Because higher temperature switching may be used, the write current may be reduced and/or switching may be performed more rapidly. As described above, this switching may occur at a magnetic thermal stability coefficient that is greater than zero in part because of the multi-phase nature of the magnetic thermal stability constant. The free layer magnetic moment is more stable after switching, during cooling of the free layer **130**. Consequently, reliability of programming the free layer **130** may be enhanced. Thus, the magnetic junction **100'"** may have improved performance.

FIG. **7** depicts another exemplary embodiment of a magnetic junction **100'"** usable in a magnetic device as well as surrounding structures. For clarity, FIG. **7** is not to scale. The magnetic junction **100'"** may be used in a magnetic device such as a STT-MRAM and, therefore, in a variety of electronic devices. The magnetic junction **100'"** is analogous to the magnetic junctions **100**, **100'**, **100"** and **100'"**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100'"** includes a reference layer **110'**, a nonmagnetic spacer layer **120**, a free layer **130**, an additional nonmagnetic spacer **140** and a reference layer **150'** that are analogous to the layers **110**/**110'**, **120**, **130**, **140** and **150** respectively, for the magnetic junctions **100**, **100'**, **100"** and **100'"**. The pinning layers **106** and **109** are omitted. In the embodiment shown in FIG. **7**, therefore, the magnetic junction **100'"** is a dual magnetic junction. The magnetic moments of the reference layers **110'** and **150'** are shown in the dual (antiparallel) state. This state may be desired for writing. In other embodiments, the magnetic moments of the reference layer **110'** and **150'** may be parallel (antidual state), which may be more desirable for read operations. In other embodiments, the magnetic moments of the layers **110'** and **150'** may be switched between the dual and antidual states depending upon the operation to be performed.

The reference layer **110'** is shown as including ferromagnetic layers **112** and **116** separated by nonmagnetic spacer layer **114**. The reference layer **110'** of FIG. **7** is thus analogous to the reference layer **110'** depicted in FIG. **6**. The reference layer **150'** is a multilayer including ferromagnetic layers **152** and **156** separated by a nonmagnetic spacer layer **154**. In other embodiments, other multilayer(s) may be used for the reference layer **150'**. Further, each layer **152**, **154**, and **156** may include sublayers. In the embodiment shown, the reference layer **150'** is a SAF in which the magnetic moments of the ferromagnetic layers **152** and **156** are coupled antiparallel. In other embodiments, the magnetic moments of the layers **152** and **156** may be coupled in another manner. Although both reference layers **110'** and **150'** are shown as multilayers, in other embodiments, one or both of the layers **110'** and **150'** may have a different structure.

The free layer **130** has multi-phase magnetic thermal stability constant analogous to that of the free layer **130** depicted in FIG. **2** and described above. In some embodiments, the magnetic thermal stability constant of the free layer **130** of FIG. **7**, may be analogous to the magnetic thermal stability constant **160**/**180** depicted in FIGS. **3**A and **3**B.

The free layer **130** of the magnetic junction **100'"** is programmed and read in an analogous manner to the free layer **130** described above. Thus, the magnetic junction **100'"** may remain stable during reading and may share the benefits of the magnetic junction **100**, **100'**, **1000"** and **100'"**. The free layer **130** may be switched using thermally assisted spin transfer torque. Thus, a more localized physical phenomenon may be used to write to the free layer **130**. Because higher temperature switching may be used, the write current may be reduced and/or switching may be performed more rapidly. As described above, this switching may occur at a magnetic thermal stability coefficient that is greater than zero at least in part because of the multi-phase nature of the magnetic thermal stability constant. The free layer magnetic moment is more stable after switching, during cooling of the free layer **130**. Consequently, reliability of programming the free layer **130** may be enhanced. Further, programming and/or reading may be enhanced by the presence of multiple reference layers **110'** and **150'**. Thus, the magnetic junction **100'''** may have improved performance.

FIG. **8** depicts an exemplary embodiment of a free layer **200** usable in a magnetic junction such as the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100''**. For clarity, FIG. **8** is not to scale. FIG. **9** is a graph depicting an exemplary embodiments of magnetic thermal stability coefficient versus temperature for the free layer **200**. The free layer **200** is configured to be switched between stable magnetic states when a write current is passed through the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100'''**. Thus, the free layer **200** is switchable utilizing spin transfer torque. The free layer **200** is also switched at an elevated temperature. Thus, thermally assisted spin transfer torque switching may be considered to be used.

The free layer **200** includes a lower temperature dependence layer **210**, a coupling layer **220** and a higher temperature dependence layer **230**. Each of the layers **210**, **220** and **230** may be a multilayer and/or an alloy. Note that although described as separate layers, in other embodiments, the layers **210** and **230** may be considered two sublattices of a free layer **200** in which the coupling layer **220** is omitted. The layers **210** and **230** are magnetic. In the embodiment shown, the layers **210** and **230** have perpendicular magnetic anisotropy energies of that exceed the out-of-plane demagnetization energies. Thus, the magnetic moments of the layers **210** and **230** may be out of plane (e.g. perpendicular-to-plane as shown in FIG. **8**). The magnetic layer **210** is closer to the nonmagnetic layer, such as the layer **120**, than the magnetic layer **230**. Thus, in embodiments in which the nonmagnetic layer is above the free layer **200**, the magnetic layer **210** is on the magnetic layer **230**. The coupling layer **220** may still be between the layers **210** and **230**. Further, although only one magnetic layer **210**, one coupling layer **220** and one magnetic layer **230** are shown, in another embodiment, more layers may be used. For example, an additional coupling layer and an additional lower temperature dependence layer may be included on the layer **230**.

The magnetic layer **210** has a lower temperature dependence. For example, the perpendicular anisotropy of the layer **210** may be primarily or completely due to a bulk perpendicular anisotropy of the material(s) used. As a result, the perpendicular anisotropy and, therefore, the magnetic thermal stability coefficient of the magnetic layer **210** may vary less with temperature. The magnetic layer **230** has a higher temperature dependence. For example, the perpendicular anisotropy of the layer **230** may be primarily or totally due to an interfacial perpendicular anisotropy of the material(s) used. Thus, the interfaces of between the magnetic layer **230** and other layers, such as the coupling layer **220**, may result in a significant portion (or all) of the perpendicular anisotropy. The perpendicular anisotropy and, therefore, the magnetic thermal stability coefficient of the magnetic layer **230** may vary more with temperature.

The magnetic layer **210** having a lower temperature dependence for the magnetic thermal stability coefficient may be configured in a variety of ways. For example, the magnetic layer **210** may include a $Co_aFe_bB_c/W/Fe/W/Co_dFe_eB_f$ multilayer. In such an embodiment, a+b+c=1, d+e+f=1, at least one of a and b is nonzero and at least one of d and e is nonzero. In some embodiments, additional repeats of CoFeB layers interleaved with and sandwiching W/Fe/W trilayers may be used. Similarly, at least one of d and e is nonzero. As a result, the layer **210** is magnetic. In other embodiments, the magnetic layer **210** may include a $Fe/Co_hFe_iB_j/W/Fe/W/Co_kFe_mB_n$ multilayer. In such an embodiment, h+i+j=1 and k+m+n=1. Further, at least one of h and i and at least one of k and m are nonzero. In the above multilayers, the CoFeB layers may have concentrations as follows: Co: 1-30 atomic percent, Fe: 40-99 atomic percent and B: 1-50 atomic percent. In some such embodiments, the CoFeB layers may have concentrations as follows: Co 10-20 atomic percent, Fe: 60-90 atomic percent and B 10-30 atomic percent. In the above multilayers in which the B concentration is zero, the CoFe layers may have concentrations as follows: Co: 1-70 atomic percent and Fe 30-99 atomic percent. In some such embodiments, the CoFe layers may have concentrations as follows: Co: 10-30 atomic percent and Fe 70-90 atomic percent. Thus, the layer **210** is magnetic. Further, additional repeats of multilayers interleaved with and sandwiching W/Fe/W trilayers may be employed. The magnetic layer **210** may also include a $Co_oFe_p/Co_qFe_rB_s/W/Fe/W/Co_tFe_uB_v$ multilayer, where o+p=1, q+r+s=1, and t+u+v=1. At least one of q and r and at least one of t and u are nonzero. Again, additional repeats of the magnetic layers separated by the W/Fe/W trilayer may also be used. Some combination of the above multilayers may also be used. In some embodiments, the magnetic layer **210** is at least five and not more than twenty Angstroms thick.

The magnetic layer **230** having a higher temperature dependence for the magnetic thermal stability coefficient may be configured in a variety of ways. The magnetic layer **230** may include a $[Co_aT_b/Pd]_i$ bilayer, where a+b=1, a is greater than zero and i is at least one (at least one repeat) and T is a nonmagnetic metal. Similarly, a $Co_aT_bPd_c$ alloy in which a+b+c=1, a is greater than zero and T is a nonmagnetic metal may be used. A $[Fe_cX_d/Pd]_j$ bilayer in which c+d=1, j is at least one, c is greater than zero and X is a nonmagnetic metal may be used. The magnetic layer **230** may include $Fe_cX_dPd_e$ alloy layer(s) in which c+d+e=1, c is greater than zero an X is a nonmagnetic metal. The magnetic layer **230** may include a $[Co_eX_f/Pt]_k$ bilayer in which e+f=1, e is greater than zero, k is at least one and X is a nonmagnetic metal. $Co_eX_fPt_j$ alloy layer(s) in which e+f+j=1, e is greater than zero and X is a nonmagnetic metal may be used. The magnetic layer **230** may include $[Fe_gZ_h/Pt]_m$ bilayer in which g+h=1, g is greater than zero, m is at least one and Z is a nonmagnetic metal. $Fe_gZ_hPt_i$ alloy layer(s) in which g+h=1, g is greater than zero and Z is a nonmagnetic metal may be used. The magnetic layer **230** may include one or more of a $[Co/Ni]_n$ bilayer where n is at least one, MnAl, MnGa, MnIn, MnGe, and RE_oQ_p where RE is a rare earth and Q is selected from Fe, Co and Ni. Where not specified, various stoichiometries that result in the desired properties may be used. The magnetic layer **230** may be at least ten Angstroms and not more than one hundred Angstroms thick.

The free layer **200** also includes coupling layer **220** that is used to control the magnetic coupling between the layers **210** and **230**. For example, the thickness and/or material(s) used in the coupling layer **220** may change the strength of the interaction between the layers **210** and **230**. The coupling layer **220** may include at least one ferromagnetic material and at least one nonmagnetic material. The ferromagnetic material(s) are selected from Fe, Co, Ni, FeCo, FeNi, and FeCoNi. The nonmagnetic material may be selected from W, Ta, V, Ge, Mn, ZN, Cu, Ga, Li, Mo, Re, Rh, Se and Ti. For example, the coupling layer **220** may include FeW at the desired stoichiometry. The coupling layer **220** may be at least four Angstroms and not more than twenty Angstroms thick. The strength of the coupling is desired to be weakly dependent on temperature.

FIG. **9** depicts a graph of the magnetic thermal stability coefficient **280** versus temperature for the free layer **200**. Although particular slopes and shapes are shown in FIG. **9**, these are explanatory purposes only and are not meant to represent specific numerical values except where noted. The magnetic thermal stability coefficient **280** includes two phases **282** and **284** that are analogous to the phases **162**/**182** and **164**/**184**, respectively. The magnetic thermal stability coefficient **280** goes to zero at T_2 and may remain zero above T_2. The magnetic thermal stability coefficient **280** is greater than zero below T_2 and has a phase transition at T_1. The first phase **282** is for temperatures below T_1, while the second phase **284** is for temperatures between T_1 and T_2. At the transition between the phases **282** and **284**, the slope of the magnetic thermal stability coefficient **280** is discontinuous. The slope of the first phase **282** and the slope of the second phase **284** differ at the transition temperature T_1. The magnetic thermal stability coefficient **280** has a sharp (phase) transition at T_1. Below T_1, the first phase **282** of the magnetic thermal stability coefficient **280** may change more rapidly. Above T_1, the second phase **284** of the magnetic thermal stability coefficient **280** may change more slowly. Thus, the slope of the first phase **282** is generally more negative than the slope of the second phase **284**.

The first phase **282** of the magnetic thermal stability coefficient **280** has components due to the magnetic layers **210** and **230**. As can be seen in FIG. **9**, a portion of the first phase **282** that varies more slowly with temperature is due to the magnetic layer **210**. A portion of the magnetic thermal stability coefficient **282** that is due to the magnetic layer **230** varies more quickly. As a result, the total magnetic thermal stability coefficient **280** varies more rapidly with temperature for the first phase **282**. After the phase transition at T_1, the magnetic thermal stability coefficient is due entirely to magnetic layer **210**. Thus, the portion of the magnetic thermal stability coefficient **280** due to the magnetic layer **230** may be considered to go to zero at T_1. The remaining portion of the magnetic thermal stability coefficient **280** due to the magnetic layer **210** may be considered to reach zero at T_2.

The free layer **200** is programmed and read in an analogous manner to the free layer **130** described above. Thus, the free layer **200** may remain stable during reading and may share the benefits of the free layer **130**. The free layer **200** may be switched using thermally assisted spin transfer torque. Thus, a more localized physical phenomenon may be used to write to the free layer **200**. Because higher temperature switching may be used, the write current may be reduced and/or switching may be performed more rapidly. As described above, this switching may occur at a magnetic thermal stability coefficient that is greater than zero at least in part because of the multi-phase nature of the magnetic thermal stability constant. The free layer magnetic moment is more stable after switching, during cooling of the free layer **200**. Consequently, reliability of programming the free layer **200** may be enhanced.

FIG. **10** depicts another exemplary embodiment of a free layer **200'** for a magnetic junction such as the magnetic junction **100**, **100'**, **100"**, **100'"** and/or **100'"**. For clarity, FIG. **10** is not to scale. The free layer **200'** is analogous to the free layer **200**. Consequently, analogous components are labeled similarly. Thus, the free layer **200'** magnetic layers **210**, coupling layer **220** and magnetic layer **230** that are analogous to the layers **210**, **220** and **230**, respectively, for the free layer **200**.

In the embodiment shown in FIG. **10**, the nonmagnetic spacer layer is on the free layer **200'**. Thus, the order of the layers **210**, **220** and **230** has been reversed from that shown in FIG. **8**. However, operation of the free layer **200** remains substantially the same. Thus, the magnetic thermal stability coefficient for the free layer **200'** may be analogous to that of the free layer **200**.

The free layer **200'** is programmed and read in an analogous manner to the free layers **130** and **200** described above. Thus, the free layer **200'** may remain stable during reading and may share the benefits of the free layer **130**. The free layer **200'** may be switched using a more localized physical phenomenon, switched at a reduced write current and/or switched more rapidly. This switching may occur at a magnetic thermal stability coefficient that is greater than zero, resulting in more stable switching. Consequently, reliability of programming the free layer **200'** may be enhanced.

FIG. **11** depicts another exemplary embodiment of a free layer **200"** for a magnetic junction such as the magnetic junction **100**, **100'**, **100"**, **100'"** and/or **100'"**. For clarity, FIG. **11** is not to scale. The free layer **200"** is analogous to the free layers **200** and **200'**. Consequently, analogous components are labeled similarly. Thus, the free layer **200"** magnetic layers **210**, coupling layer **220** and magnetic layer **230** that are analogous to the layers **210**, **220** and **230**, respectively, for the free layer **200**.

The free layer **200"** also includes an additional coupling layer **240** and an additional lower temperature dependence magnetic layer **250**. The coupling layer **240** is analogous to the coupling layer **220**. The magnetic layer **250** is analogous to the magnetic layer **210**. Thus, structure for the magnetic layer **250** may be selected from the same structures as for the magnetic layer **210**. However, the layers **210** and **250** need not be identical in a particular free layer **200"**.

The free layer **200"** is programmed and read in an analogous manner to the free layers **130**, **200** and **200'** described above. The free layer **200"** may be particularly desirable for use in a dual junction. Thus, the free layer **200"** may remain stable during reading and may share the benefits of the free layer **130**. The free layer **200"** may be switched using a more localized physical phenomenon, switched at a reduced write current and/or switched more rapidly. This switching may occur at a magnetic thermal stability coefficient that is greater than zero, resulting in more stable switching. Consequently, reliability of programming the free layer **200"** may be enhanced.

FIG. **12** depicts another exemplary embodiment of a free layer **200'"** for a magnetic junction such as the magnetic junction **100**, **100'**, **100"**, **100'"** and/or **100'"**. For clarity, FIG. **12** is not to scale. The free layer **200""** is analogous to the free layers **200**, **200'** and **200"**. Consequently, analogous components are labeled similarly. Thus, the free layer **200'"** magnetic layers **210**, coupling layer **220** and magnetic layer **230** that are analogous to the layers **210**, **220** and **230**, respectively, for the free layer **200**.

The free layer **200"** also includes an enhancement layer **260**. For example, the layer **260** may be a high Heisenberg exchange layer **260**. The enhancement layer is between the magnetic layer **210** and the nonmagnetic spacer layer (not shown). The enhancement layer **260** is generally desired to be a pure ferromagnetic alloy (or element) with no nonmagnetic constituents. Examples of such materials that may be used in the enhancement layer **260** include but are not limited Fe, CoFe (with various concentrations), Ni, NiFe (with various concentrations), CoNi (with various concentrations), Co, FeMn (with various concentrations), CoMn (with various concentrations) and NiMn (with various concentrations). The enhancement layer **260** is thus desired to be ferromagnetic.

The free layer **200'''** is programmed and read in an analogous manner to the free layers **130**, **200**, **200'** and **200"** described above. Thus, the free layer **200'''** may remain stable during reading and may share the benefits of the free layer **130**. The free layer **200'''** may be switched using a more localized physical phenomenon, switched at a reduced write current and/or switched more rapidly. This switching may occur at a magnetic thermal stability coefficient that is greater than zero, resulting in more stable switching. Consequently, reliability of programming the free layer **200'''** may be enhanced.

FIG. **13** depicts another exemplary embodiment of a free layer **200'''** for a magnetic junction such as the magnetic junction **100**, **100'**, **100"**, **100'''** and/or **100'''**. For clarity, FIG. **13** is not to scale. The free layer **200'''** is analogous to the free layers **200**, **200'**, **200"** and **200'''**. Consequently, analogous components are labeled similarly. Thus, the free layer **200'''** magnetic layers **210**, coupling layer **220**, magnetic layer **230** and enhancement layer **260** that are analogous to the layers **210**, **220**, **230**, and **260**. Although the order of the layers **210**, **220**, **230** and **260** with respect to a nonmagnetic spacer is unchanged, the order with respect to an underlying substrate has been reversed.

The free layer **200'''** is programmed and read in an analogous manner to the free layers **130**, **200**, **200'**, **200"** and **200'''** described above. Thus, the free layer **200'''** may remain stable during reading and may share the benefits of the free layer **130**. The free layer **200'''** may be switched using a more localized physical phenomenon, switched at a reduced write current and/or switched more rapidly. This switching may occur at a magnetic thermal stability coefficient that is greater than zero, resulting in more stable switching. Consequently, reliability of programming the free layer **200'''** may be enhanced.

FIG. **14** depicts another exemplary embodiment of a free layer **200'''''** for a magnetic junction such as the magnetic junction **100**, **100'**, **100"**, **100'''** and/or **100'''**. For clarity, FIG. **14** is not to scale. The free layer **200'''''** is analogous to the free layers **200**, **200'**, **200"**, **200'''** and **200'''**. Consequently, analogous components are labeled similarly. Thus, the free layer **200'''''** magnetic layers **210**, coupling layer **220**, magnetic layer **230**, coupling layer **240**, magnetic layer **250** and enhancement layer **260** that are analogous to the layers **210**, **220**, **230**, **240**, **250** and **260**, respectively.

The free layer **200'''''** also includes an enhancement layer **270** that is analogous to the enhancement layer **260**. For example, the layer **270** may be a high Heisenberg exchange layer. The enhancement layer is between the magnetic layer **250** and an additional nonmagnetic spacer layer (not shown).

The free layer **200'''''** is programmed and read in an analogous manner to the free layers **130**, **200**, **200'**, **200"** and **200'''** described above. The free layer **200'''''** may be particularly desirable for use in a dual junction. The free layer **200'''''** may remain stable during reading and may share the benefits of the free layer **130**. The free layer **200'''''** may be switched using a more localized physical phenomenon, switched at a reduced write current and/or switched more rapidly. This switching may occur at a magnetic thermal stability coefficient that is greater than zero, resulting in more stable switching. Consequently, reliability of programming the free layer **200'''''** may be enhanced.

FIG. **15** depicts an exemplary embodiment of a method **290** for fabricating a magnetic junction. For simplicity, some steps may be omitted or combined. The method **290** is described in the context of the magnetic junctions **100**, **100'**, **100"**, **100'''** and **100'''**. However, the method **290** may be used on other magnetic junctions. Further, the method **290** may be incorporated into fabrication of magnetic memories. Thus the method **290** may be used in manufacturing a STT-MRAM or other magnetic memory.

The reference layer **110/110'** that may be a SAF is provided, via step **291**. Step **291** may include depositing the desired materials at the desired thickness of the reference layer **110/110'**. The nonmagnetic layer **120** is provided, via step **292**. Step **292** may include depositing the desired nonmagnetic materials. In addition, the desired thickness of material may be deposited in step **292**. The free layer **130//200/200'/200"/200'''/200'''/200'''''** is provided, via step **293**. Step **293** thus includes depositing the material(s) which result in a multi-phase magnetic thermal stability coefficient. Thus, multilayer(s) or alloy(s) with sublattices may be provided in step **293**. The nonmagnetic layer **140** may optionally be provided, via step **294**. The desired reference layer **150/150'** may optionally be provided, via step **295**. Fabricating of the magnetic junction **100**, **100'**, **100"**, **100'''** and/or **100'''** may then be completed, via step **296**. Consequently, the benefits of the magnetic junction(s) **100**, **100'**, **100"**, **100'''** and/or **100'''** as well as the benefits of the free layers **130**, **130'**, **200**, **200'**, **200"**, **200'''**, **200'''** and/or **200'''''** may be achieved.

FIG. **16** depicts an exemplary embodiment of a memory **300** that may use one or more of the magnetic junctions **100**, **100'**, **100"**, **100'''** and/or **100'''** and the free layers **130**, **200**, **200'**, **200"**, **200'''**, **200'''** and/or **200'''''**. The magnetic memory **300** includes reading/writing column select drivers **302** and **306** as well as word line select driver **304**. Note that other and/or different components may be provided. The storage region of the memory **300** includes magnetic storage cells **310**. Each magnetic storage cell includes at least one magnetic junction **312** and at least one selection device **314**. In some embodiments, the selection device **314** is a transistor. The magnetic junctions **312** may be one of the magnetic junctions **100**, **100'**, **100"**, **100'''** and/or **100'''** and the free layers **130**, **200**, **200'**, **200"**, **200'''**, **200'''** and/or **200'''''**. Thus, the free layer of the magnetic junctions **312** has a multi-phase magnetic thermal stability coefficient. Although one magnetic junction **312** is shown per cell **310**, in other embodiments, another number of magnetic junctions **312** may be provided per cell. Further, although not shown, in some embodiments, the memory **300** may include heaters and associated electronics or some other mechanism used to heat the magnetic junctions **312**. Elevated temperatures of the magnetic junctions **312** during programming allow for operation as discussed above. As such, the magnetic memory **300** may enjoy the benefits described above.

FIG. **17** depicts an exemplary embodiment of a method **400** for programming a magnetic junction. For simplicity, some steps may be omitted or combined. The method **400** is described in the context of the magnetic junctions **100**, **100'**, **100"**, **100'''** and **100'''**. However, the method **400** may be used on other magnetic junctions.

A write current is driven through the free layer at elevated temperatures, via step **402**. This is performed at least for the free layer temperatures corresponding to a portion of the second phase of the magnetic thermal stability coefficient. Further, the temperatures for which current is driven through the magnetic junction correspond to magnetic thermal stability coefficients that are greater than zero. For example, the free layer magnetic thermal stability coefficient may be at least twenty and not more than forty for at least part of step

402. Note that step **402** does not indicate how the free layer is heated for step **402**. The heating may be accomplished using the write current only. In such embodiments, the write current is terminated before the magnetic thermal stability coefficient reaches zero. In other embodiments, heating may also involve a separate heat source, such as a current driven through a heater. In such embodiments, both the write current and heater power are terminated before the magnetic thermal stability coefficient reaches zero.

Using the method **400**, the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100'''** may be more reliably and easily written. Because the write current is driven through the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100'''** at elevated temperatures and lower magnetic thermal stability coefficients, switching may be more rapidly achieved at lower temperatures. In addition, because the write current is terminated while the magnetic thermal stability coefficient is nonzero, switching is more stable. Thus performance and reliability of the write operation may be improved.

FIG. **18** depicts an exemplary embodiment of a method **410** for fabricating a magnetic junction. For simplicity, some steps may be omitted or combined. The method **410** is described in the context of the magnetic junctions **100**, **100'**, **100''**, **100'''** and **100'''**. However, the method **410** may be used on other magnetic junctions.

The free layer is heated to temperature(s) corresponding to a phase that has a reduced temperature dependence, via step **412**. Step **412** may be accomplished using a heater or by driving the write current through the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100'''**.

A write current is driven through the free layer at elevated temperatures and terminated before the magnetic thermal stability coefficient reaches zero, via step **414**. For example, the write current may be terminated while the magnetic thermal stability coefficient is at least twenty.

Using the method **410**, the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100'''** may be more reliably and easily written. Because the write current is driven through the magnetic junction **100**, **100'**, **100''**, **100'''** and/or **100'''** at elevated temperatures and lower magnetic thermal stability coefficients, switching may be more rapidly achieved at lower temperatures. In addition, because the write current is terminated while the magnetic thermal stability coefficient is nonzero, switching is more stable. Thus performance and reliability of the write operation may be improved.

A method and system for providing a magnetic junction and an electronic device, such as one including a memory fabricated using the magnetic junction, has been described. The method and system have been described in accordance with the exemplary embodiments shown, and one of ordinary skill in the art will readily recognize that there could be variations to the embodiments, and any variations would be within the spirit and scope of the method and system. Accordingly, many modifications may be made by one of ordinary skill in the art without departing from the spirit and scope of the appended claims.

We claim:

1. A magnetic junction for use in a magnetic device comprising:

at least one reference layer;

at least one nonmagnetic spacer layer; and

a free layer, the at least one nonmagnetic spacer layer being between the free layer and the at least one reference layer, the free layer having a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases, a first phase magnetic thermal stability coefficient of the plurality of

magnetic thermal stability coefficient phases having a first slope below a first temperature, a second phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a second slope above the first temperature and below a second temperature, the second temperature being greater than the first temperature, the magnetic thermal stability coefficient being zero above the second temperature and greater than zero below the second temperature, the first slope and second slope being unequal at the first temperature;

wherein the free layer is switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction.

2. The magnetic junction of claim **1** wherein the second phase magnetic thermal stability coefficient goes to zero at the second temperature.

3. The magnetic junction of claim **1** wherein the second temperature is at least one hundred degrees Celsius.

4. The magnetic junction of claim **1** wherein the free layer is configured to be written at a write temperature above the first temperature, below the second temperature and corresponding to the second phase magnetic thermal stability coefficient being at least twenty and not more than forty.

5. The magnetic junction of claim **1** wherein at least a portion of the first slope is more negative than at least a portion of the second slope.

6. A magnetic junction for use in a magnetic device comprising:

at least one reference layer;

at least one nonmagnetic spacer layer; and

a free layer, the at least one nonmagnetic spacer layer being between the free layer and the at least one reference layer, the free layer having a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases, a first phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a first slope below a first temperature, a second phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a second slope above the first temperature and below a second temperature, the second temperature being greater than the first temperature, the magnetic thermal stability coefficient being zero above the second temperature and greater than zero below the second temperature, the first slope and second slope being unequal at the first temperature;

wherein the free layer is switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction

wherein the first temperature is at least one hundred fifty degrees Celsius and not more than two hundred degrees Celsius and wherein the second temperature is at least three hundred and not more than eight hundred degrees Celsius.

7. A magnetic junction for use in a magnetic device comprising:

at least one reference layer;

at least one nonmagnetic spacer layer; and

a free layer, the at least one nonmagnetic spacer layer being between the free layer and the at least one reference layer, the free layer having a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases, a first phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a first slope below a first temperature, a second phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a second slope above the first temperature and below a second temperature, the second temperature being greater than the first temperature, the magnetic thermal stability coefficient being zero above the second temperature and greater than zero below the second temperature, the first slope and second slope being unequal at the first temperature, the free layer including a plurality of magnetic layers, a first magnetic layer of the plurality of magnetic layers corresponding to a first portion of the first phase magnetic thermal stability coefficient, a second magnetic layer of the plurality of magnetic layers having the second phase magnetic thermal stability coefficient and corresponding to a second portion of the first phase magnetic thermal stability coefficient;

wherein the free layer is switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction.

8. The magnetic junction of claim **7** wherein and the second magnetic layer is closer to the at least one nonmagnetic spacer than the first magnetic layer.

9. The magnetic junction of claim **7** wherein the free layer further includes at least one insertion layer between the second layer and the at least one nonmagnetic spacer layer.

10. The magnetic junction of claim **7** wherein the plurality of magnetic layers are interleaved with at least one coupling layer.

11. The magnetic junction of claim **10** wherein the coupling layer includes at least one ferromagnetic material and at least one nonmagnetic material, the at least one ferromagnetic material being selected from Fe, Co, Ni, FeCo, FeNi, and FeCoNi and the at least one nonmagnetic material being selected from W, Ta, V, Ge, Mn, ZN, Cu, Ga, Li, Mo, Re, Rh, Se and Ti.

12. The magnetic junction of claim **7** wherein the first magnetic layer includes at least one of a $[Co_aT_b/Pd]_i$ bilayer, $Co_cT_dPd_e$, a $[Fe_fX_g/Pd]_j$ bilayer, $Fe_hX_lPd_o$, a $[Co_pY_q/Pt]_k$ bilayer, $Co_rY_sPt_t$, a $[Fe_uZ_v/Pt]_m$ bilayer, $Fe_wZ_xPt_y$, a $[Co/Ni]_n$ bilayer, MnAl, MnGa, MnIn, MnGe, and RE_oQ_p where i, j, k, m and n are integers greater than zero, where T, X, Y and Z are nonmagnetic metals, wherein RE is a rare earth and Q is selected from Fe, Co and Ni, where a+b=1, c+d+e=1, f+g=1, h+l+o=1, p+q=1, r+s+t=1, u+v=1, w+x+y=1 and where a, c, f, h, o, r, u and w are all greater than zero.

13. The magnetic junction of claim **7** wherein the second magnetic layer includes at least one of a $Co_aFe_bB_c/W/Fe/W/Co_dFe_eB_f$ multilayer, a $Fe/Co_hFe_iB_j/W//Fe/W/Co_kFe_mB_n$ multilayer, a $Co_oFe_p/Co_qFe_rB_s/W/Fe/W/Co_tFe_uB_v$ multilayer, where a+b+c=1, d+e+f=1, h+i+j=1, k+m+n=1, o+p=1, q+r+s=1, t+u+v=1 and where a, b, d, e, h, l, k, m, o, p, q, r, t and u are greater than zero.

14. The magnetic junction of claim **7** wherein the first magnetic layer is magnetically coupled with the second magnetic layer.

15. A magnetic junction for use in a magnetic device comprising:

at least one reference layer;

at least one nonmagnetic spacer layer; and

a free layer, the at least one nonmagnetic spacer layer being between the free layer and the at least one reference layer, the free layer having a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases, a first phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a first slope below a first temperature, a second phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a second slope above the first temperature and below a second temperature, the second temperature being greater than the first temperature, the magnetic thermal stability coefficient being zero above the second temperature and greater than zero below the second temperature, the first slope and second slope being unequal at the first temperature, the first phase having a first portion and a second portion, the first portion reaching zero at the first temperature, the second phase magnetic thermal stability coefficient reaching zero at the second temperature, the second phase magnetic thermal stability coefficient corresponding to the second portion of the first magnetic thermal stability coefficient below the first temperature; and

wherein the free layer is switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction.

16. An electronic device comprising:

a magnetic memory including a plurality of magnetic storage cells and a plurality of bit lines, each of the plurality of magnetic storage cells including at least one magnetic junction, the at least one magnetic junction including at least one reference layer, at least one nonmagnetic spacer layer, and a free layer, the at least one nonmagnetic spacer layer being between the free layer and the at least one reference layer, the free layer having a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases, a first phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a first slope below a first temperature, a second phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a second slope above the first temperature and below a second temperature, the second temperature being greater than the first temperature, at least a portion of the first slope being more negative than at least a portion of the second slope, the first slope and the second slope being unequal at the first temperature the magnetic thermal stability coefficient being zero above the second temperature and greater than zero below the second temperature, the at least one magnetic junction being configured such that the free layer is switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction;

wherein the free layer includes a plurality of magnetic layers interleaved and sandwiching with at least one coupling layer, a first magnetic layer of the plurality of magnetic layers having the first phase magnetic thermal stability coefficient and a second magnetic layer of the plurality of magnetic layers having the second phase magnetic thermal stability coefficient.

17. A method for programming a magnetic junction for use in a magnetic device comprising:

driving a write current through a magnetic junction including at least one reference layer, a free layer switchable between a plurality of stable magnetic states when the write current is passed through the magnetic junction and at least one nonmagnetic spacer layer between the free layer and the at least one reference layer, the free layer having a magnetic thermal stability coefficient having a plurality of magnetic thermal stability coefficient phases, a first phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a first slope below a first temperature, a second phase magnetic thermal stability coefficient of the plurality of magnetic thermal stability coefficient phases having a second slope above the first temperature and below a second temperature, the first slope and the second slope being unequal at the first temperature, the magnetic thermal stability coefficient being zero above the second temperature and greater than zero below the second temperature, the second temperature being greater than the first temperature, at least a portion of the first slope being more negative than at least a portion of the second slope;

wherein the free layer reaches a write temperature between the first temperature and the second temperature during the step of driving the write current; and

wherein the write temperature corresponds to the magnetic thermal stability coefficient being at least twenty and not more than forty.

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